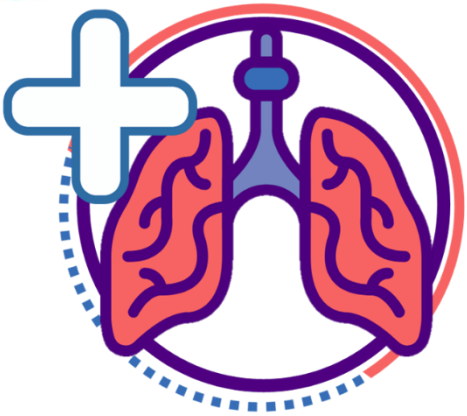

RESPIRATORY SYSTEM

Physiology

Sheet Slide

Number:	-2
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Respiratory System - Physiology

Last lecture , we divided Hypoxia into : Hypoxic Hypoxia (Not enough available oxygen to lungs due to high altitude or airway obstruction for example) , Anemic Hypoxia(Not enough functional Hb to carry Oxygen) Stagnant Hypoxia (Obstruction of Arteries) and Histotoxic Hypoxia (Problem's in the cell itself such as Mitochondrial defects or poisoning the respiratory chain by Cyanide)

However , Another way to divide Hypoxia is to Pulmonary (Caused by the Lung) and Extra-Pulmonary (Not caused by the lung) . If you have a hypoxic patient , how can we know which type he/she has ?

We Perform an **Arterial Blood Gases (ABGs) Test :** in which we take an arterial blood sample (usually from the radial artery) and analyse the partial pressure of gases . If the PO2 equals 100mmHg and the PCO2 equals 40mmHg , then the patient has Extra-Pulmonary Hypoxia (The lung is doing its Job))(So remember , Normal ABG does not rule out Hypoxia , it just says that Hypoxia is Extra-Pulmonary- CO poisoning is an example)

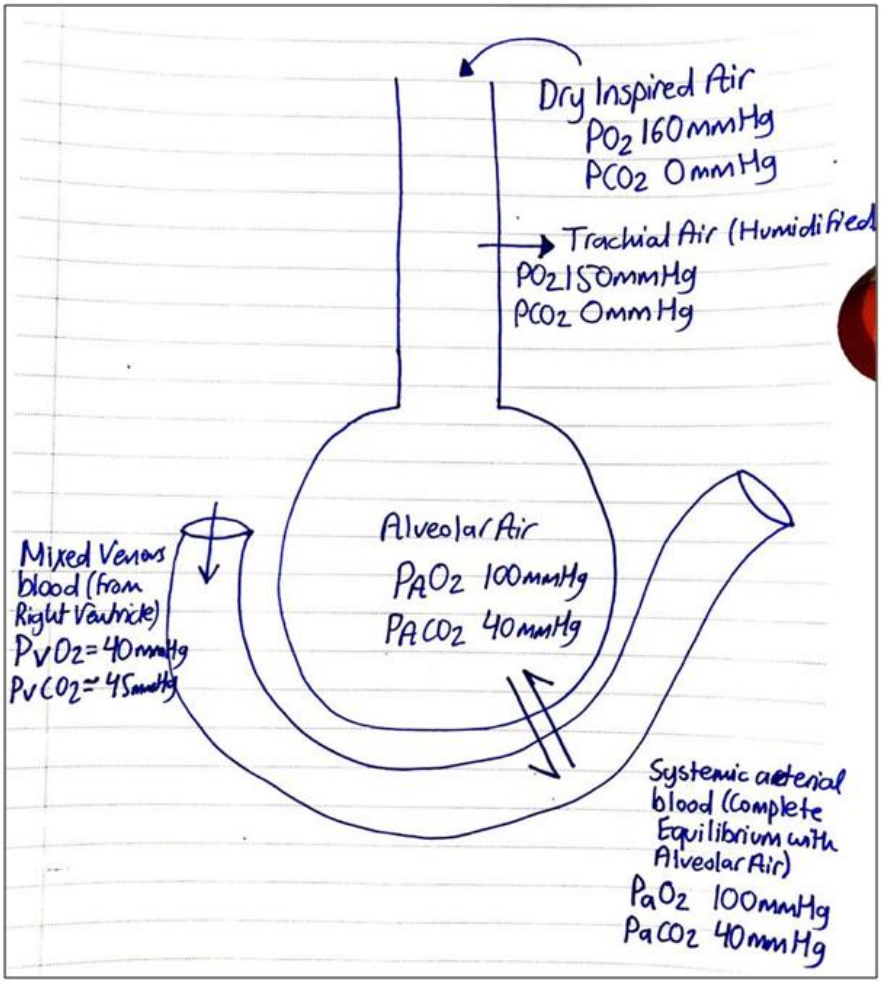
However if the PO2 was less than 100mmHg or the PCO2 was more than 40mmHg , the patient likely has pulmonary hypoxia (but still not 100% as we can get these abnormal readings in some extra-pulmonary cases such as high altitude).

Deep Look : Overview to Gases Composition in RS (Resting Phase – After inspiration/before expiration) :

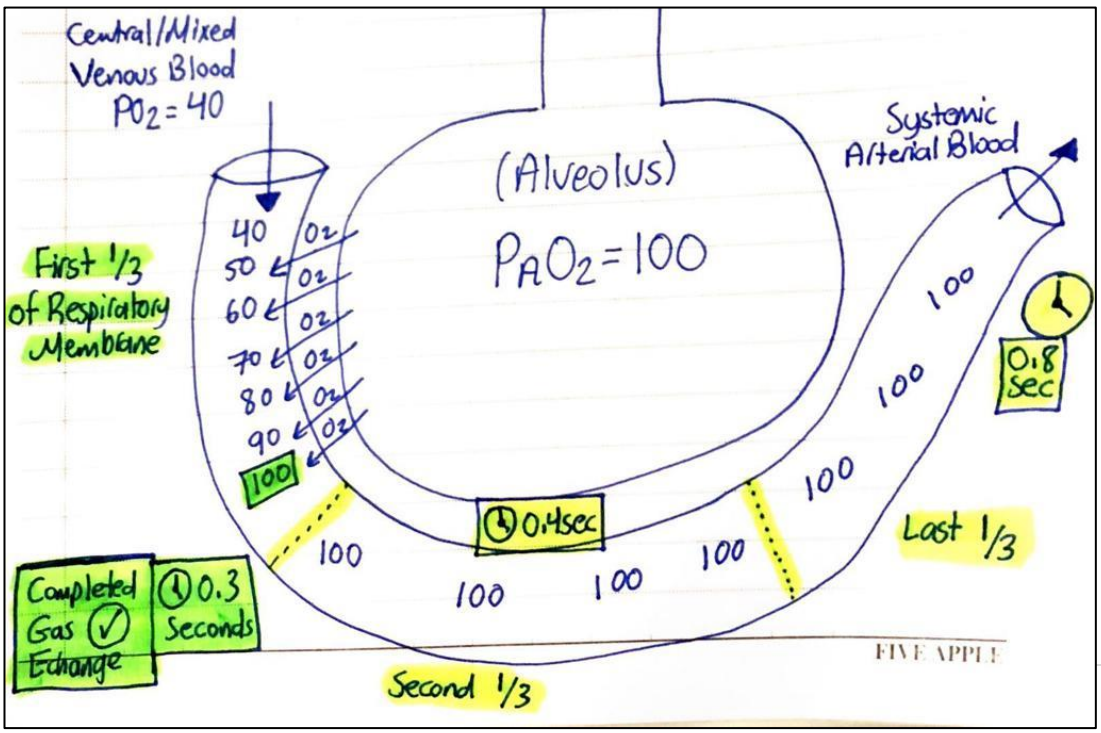
Area	PO2 (mmHg)	PCO2 (mmHg)
Outside Atmosphere	160	0
Tracheal Air	150	0
Alveolar Air	100	40
Systemic Arterial Blood	100	40
Central/Mixed Venous Blood	40	45

We notice that the PO2 greatly drops and PCO2 greatly increases in Alveolar Air , this is because at this level gas exchange occurs (O2 leaves the alveolar air to the capillary and CO2 leaves the capillary to the Alveolar air explaining the changes) . However we also notice that

Alveolar air and systemic arterial blood are *in equilibrium* *and also have equal gas partial pressures.*

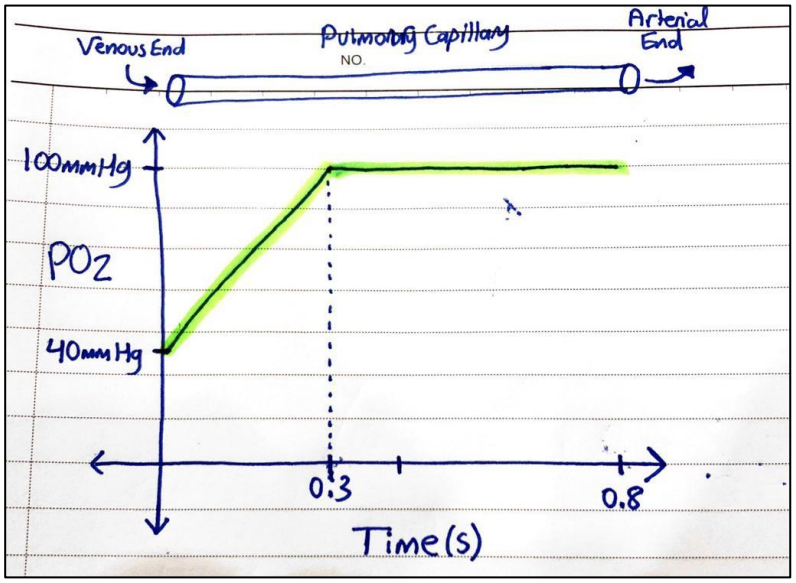


Deep Look : Changes in PO2 During Gas Exchange



We can See the following Points :

- For Full oxygen saturation , we only normally need the first third of the respiratory membrane , which in time is equal to nearly 0.3 seconds (1/3 of the Cardiac Cycle Time 0.8)
- This is beneficial because lets say someone has a problem in his lung (Destruction / removal of part due to cancer ,,etc) , he/she can still survive because we have a good lung reserve (other unused 2/3)

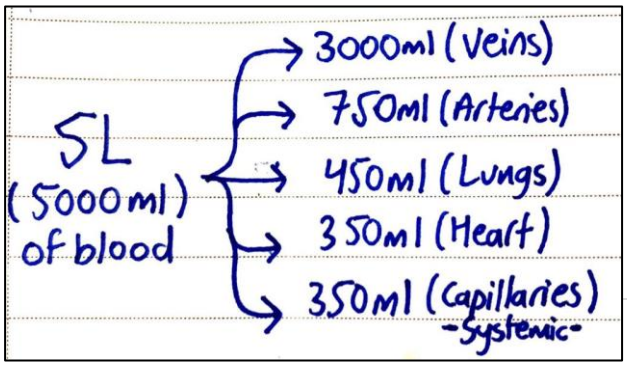


- Also during exercise , when the heart rate increases from 75 to 150 Bpm , the cardiac cycle time will decrease to 0.4 , which is more than enough for full oxygenation (That's why ABG's remain normal during exercise) But if Heart rate jumps to 300Bpm , Cardiac cycle time will decrease to 0.2 which is not enough for full oxygenation.

Now why is Alveolar PO2 equal to Arterial PO2 ? At the first glance , someone may think that as the oxygen leaves the alveoli to the capillaries , the PO2 of the alveoli should fall and the PO2 of the capillary should rise to a point in between ,, however that is not the case as both of them become 100mmHg ,, How does The alveoli lose oxygen and still keeps its PO2 100mmHg !?It's all about the Volume :

Roughly , Blood is equal to 7% of the body weight (for example 7% of 70kg person is nearly 5L of blood)

These are distributed as following :



The most important component is the systemic capillaries; as they are the site of direct contact with cells (exchange of materials),while others are just

working to keep the capillary bed fresh(Arteries sending blood to capillaries and veins taking it away , lungs for gas exchange and heart to pump everything) So the Dr divides blood compartments into Capillaries (350ml) and All others which serve the capillaries (4650ml) .

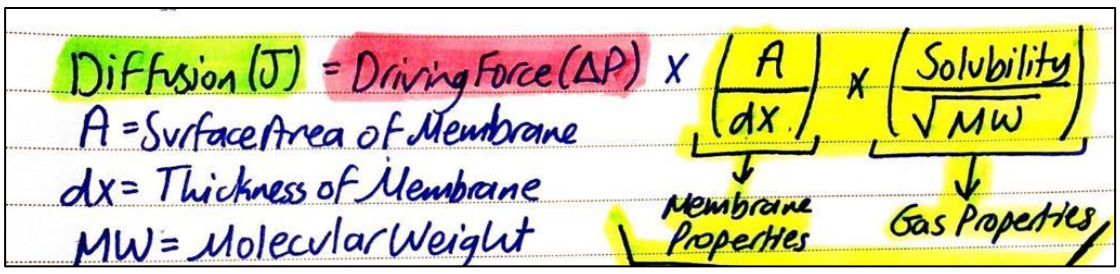
Now back to the Lung , if we take the 450ml of blood , we will find 190ml in pulmonary arteries and another 190ml in pulmonary veins leaving only 70 ml in pulmonary capillaries .

Going back to the question of why is Alveolar PO2 equal to Arterial PO2? By comparing the Alveolar Air Volume at rest (2200ml) with the Pulmonary Capillary volume (70ml) , it makes total sense now that we can't assume the PO2 to be somewhere between 40 and 100 , as **the partial pressures of the huge volume will be affected only slightly** decreasing the PO2 of the alveoli a little bit below 100mmHg , while the **small volume capillaries partial pressures are highly affected** as their PO2 jumps to 100mmHg . And Even the slight decrease in Alveolar PO2 is compensated by continuous ventilation and supply of O2 from the outside *. So its 2 factors making the alveolar and arterial PO2 equal ; Firstly the huge volume difference , Secondly the continuous ventilation.*

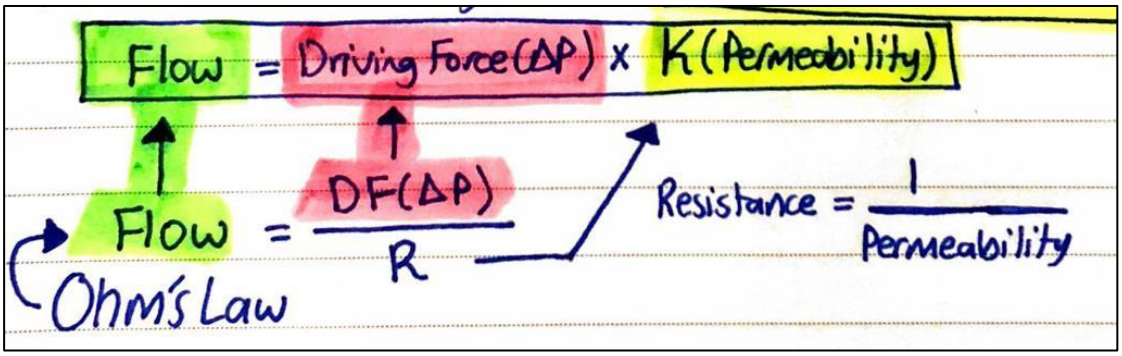
So after this point , we can easily conclude that Oxygen Gas exchange is Normally **not Diffusion limited** (as we already had an Alveolar PO2 of 100 and oxygen diffused very smoothly as if the membrane doesn't exist to make the arterial PO2 100) So if we need more oxygen , making the diffusion easier will not help because it is already easiest possible ! (This is normally , but if the respiratory membrane is thickened for example in pulmonary edema , it becomes diffusion limited as arterial PO2 won't reach 100 due to incomplete oxygenation).

But it is Perfusion Limited , so If we need more oxygen , supply more blood to the lung (Increase the cardiac output).

Deep Look : Diffusion and Ohm's Law



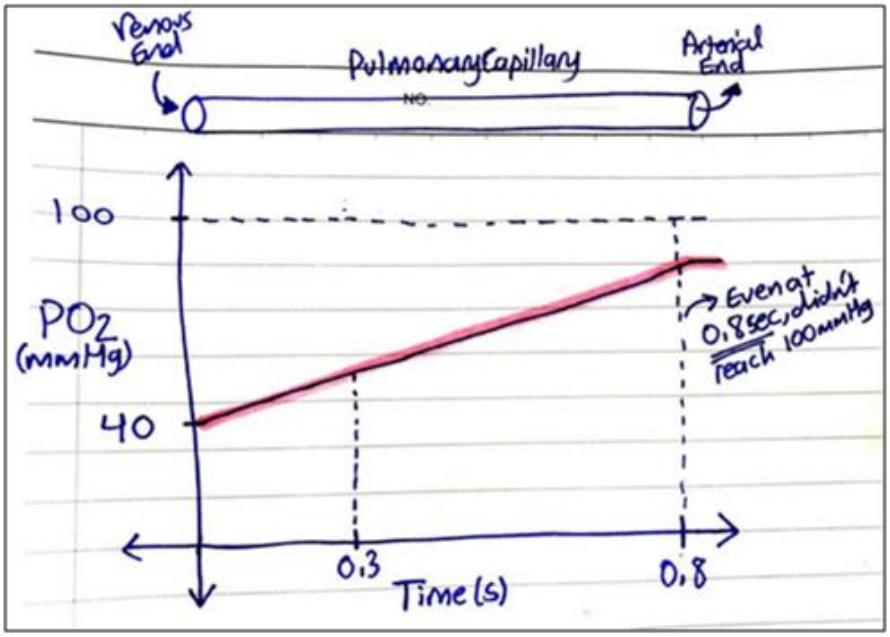
- Notice that the molecular weight is the least important factor because its under the square root .
- And because diffusion is a type of Flow , and because Resistance is inversely proportional to permeability , then according to Ohm's law , Flow = Driving Force * Permeability



- And By comparing both equations , we conclude that Permeability equals = $\left(\frac{A}{dx}\right) \times \left(\frac{Solubility}{\sqrt{Molecular\ Weight}}\right)$
- Solubility is the factor that makes CO2 *20 <u>times more diffusible</u>* than O2 as it is 20 times more soluble , which means it needs less than 1/3 of the respiratory membrane to complete its exchange (less than 0.3 seconds)

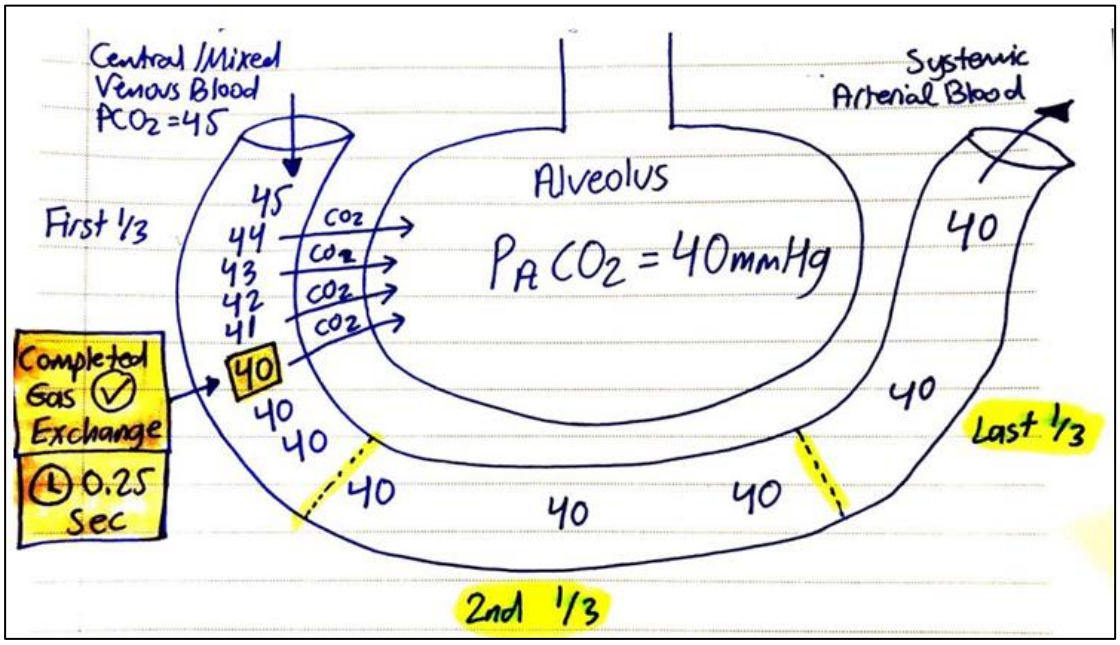
Deep Look : Abnormal case where Oxygen exchange is diffusion Limited

In this picture , we notice that gas exchange occurs along the whole respiratory membrane (whole 0.8 sec) and even after 0.8 seconds ,we didn't reach full oxygenation , this means that there is an abnormality in the respiratory membrane decreasing its diffusion ability to oxygen ; for example an increase in



membrane thickness due to pulmonary edema , fibrosis , infiltration of any substance such as what is seen in asbestosis and silicosis ,, etc . This means that what we said in the past about " if we need more oxygen , making the diffusion easier will not help because it is already easiest possible " is Not true now , as the diffusion is Not easiest possible , and if we treat the underlying problem , diffusion will improve and Oxygen gas exchange will improve **meaning that in these abnormalities; Oxygen exchange is Diffusion Limited** .

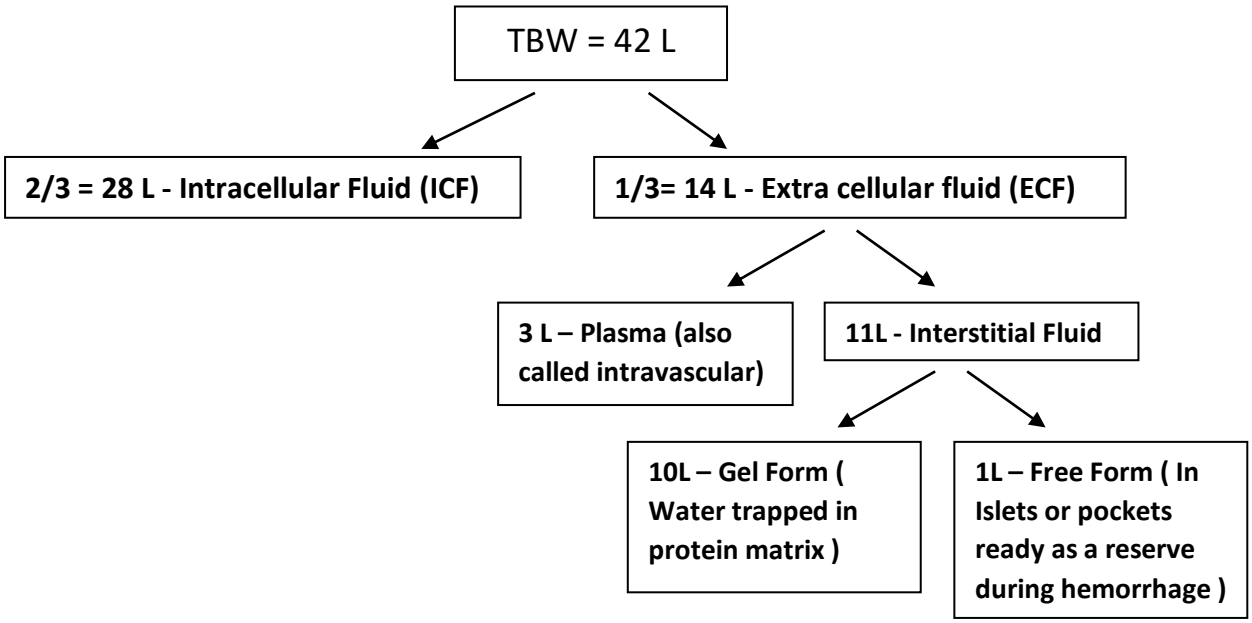
Deep Look : CO2 Exchange



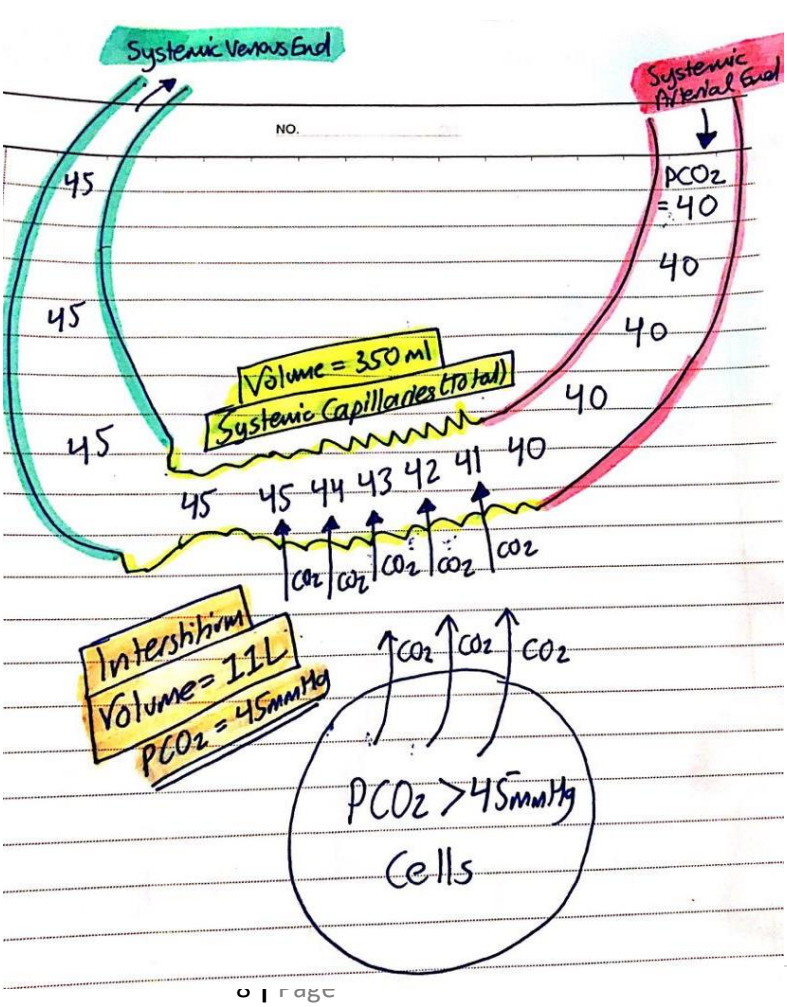
Notice that CO2 reaches equilibrium between capillary PCO2 and Alveolar PCO2 even earlier than Oxygen (due to its higher diffusability as we mentioned) , which means completing CO2 exchange before the end of the first third of the respiratory membrane (before 0.3 sec , at 0.25 sec)(Also remember that because of the large volume difference and continuous ventilation ,capillary PCO2 drops to 40 while the alveolar PCO2 doesn't increase above 40 – **Partial pressures of Huge volume not affected**)

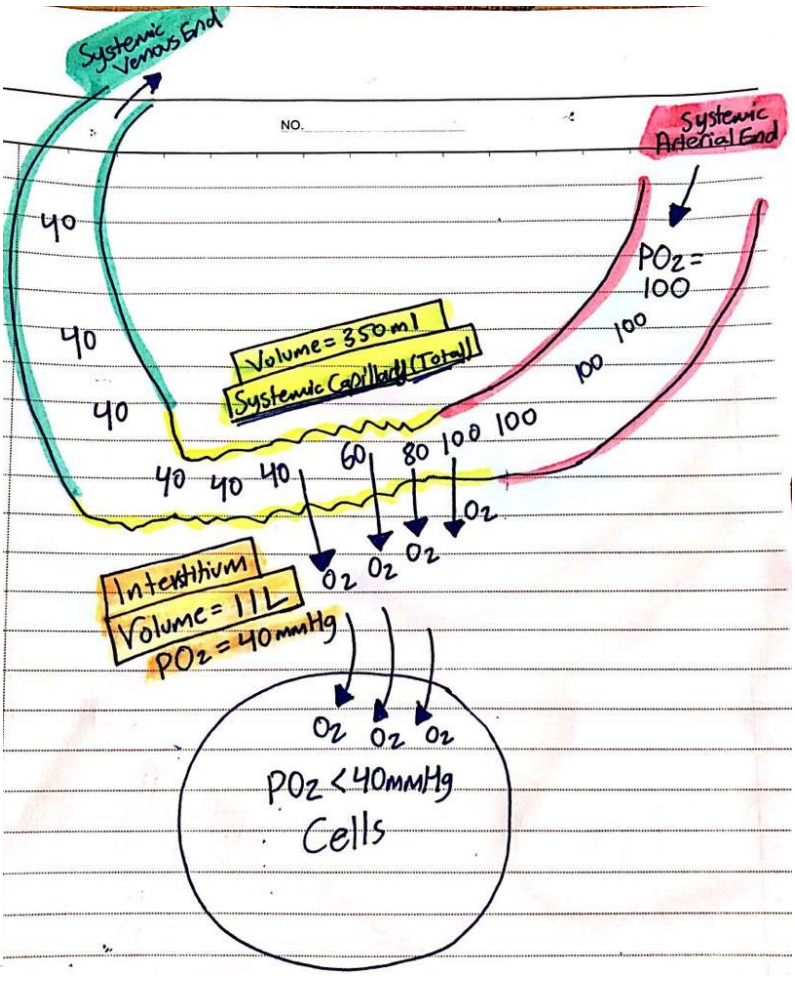
Revision to Water distribution in our body :

Total body Water (TBW)(In Liters) = 60% of persons weight(in Kg)
So for a 70Kg person , TBW = 42 L



Deep Look : Systemic Capillary Exchange:





We notice that in the Systemic Capillary gas exchange , the capillary bed blood has lower volume (350ml) than the Interstitium (11L) , which means that the PO2 and PCO2 of the large volume interstitium will only be affected slightly after gas exchange (PO2 stays 40 and PCO2 stays 45mmHg) , while the low volume systemic capillaries are highly affected; as the PO2 falls from 100 to 40 and the PCO2 Rises from 40 to 45 mmHg.

Also Notice that the PO2 of cells is lesser than 40mmHg to allow O2 that has diffused from capillaries into the interstitium , to enter inside the cell , and the other way around for CO2 , PCO2 of cells is larger than 45mmHg , to allow diffusion of CO2 into the interstitium then into the capillaries.

Deep Look : Composition of RS Air during inspiration/expiration :

Going back to the figure and table at the beginning of the *lecture which represent the resting (after inspiration / before expiration) phase* , we will see the changes of Air composition during inspiration/expiration .

First of all ; As the Cardiac Output = Heart Rate * Stroke Volume

Respiratory Minute Ventilation (RMV) = Respiratory Rate(RR) * Tidal Volume (VT) ; where RMV is the volume of air that enters or leaves the RS per min. And Tidal Volume is the volume of air that enters or leaves the RS per breath. Normal RR is around 12 , and normal VT is 500ml , which makes the normal RMV = 12*500 = 6L/min .

However , its very important to understand that the 500ml VT that we take in each breath doesn't fully reach the alveoli , as always 150ml is trapped in the anatomic dead space and 350 ml is reaching the alveoli only , so on the scale of the RMV , Alveolar Minute ventilation = 350*12 = 4.2L and Dead Space Minute Ventilation = 150*12 = 1.8 L .(Together = 6L)

Starting from this point , we will dig deep into the changes in gas composition . Depending on the resting phase in the beginning of the lecture , lets start Expiration followed by inspiration :

Remember : Alveolar Air = Old air = Air after gas exchange (P02=100 and PCO2= 40) While Fresh air (PO2 = 150-160 and PCO2=0)

1. We will push out 500ml of alveolar air outside the alveoli to airways .
2. This will push the 150ml Fresh tracheal air in the anatomic dead space to the atmosphere .
3. Followed by 350ml of the alveolar air to the atmosphere(So total 500ml expired is now reached)
4. 150ml Alveolar Air is kept in the anatomic Dead space **at the end of Expiration** .
5. Inspiration starts by inhaling 500ml of fresh air from atmosphere into the airways
6. This will push the 150 ml of Old Alveolar air (left from the preceding expiration- step 4) into the alveoli
7. Followed by the entrance of 350ml of Fresh air into the Alveoli
8. 150 ml of fresh air is kept in the anatomic Dead space **at the end of inspiration** (Going back to the resting phase – Figure at the beginning of lecture)

   Take a look at a drawing I made for the 8 steps next page.
   Green = Fresh Air
   Red = Alveolar Air

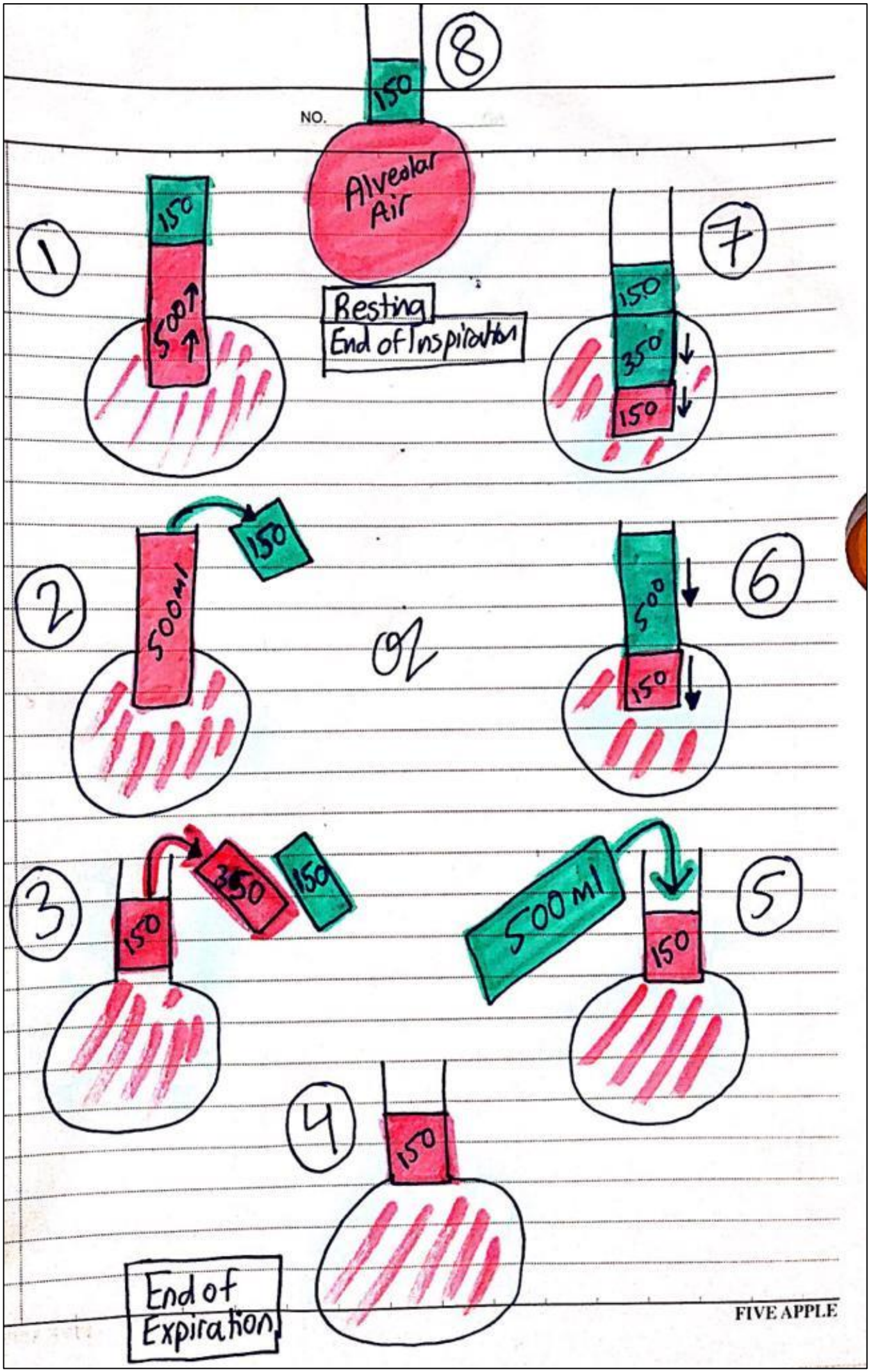
Note : Tracheal Humidified Air is treated as if it is atmospheric fresh air (PO2 drop from 160mmHg to 150mmHg is due to additional water vapour in the Airways)

Deep Look : Composition of RS Air during CPR - Artificial Ventilation (Mouth to Mouth Ventilation)

To understand this process , think of it as if the person who is performing CPR is giving his/hers **expiratory mixed air** to the patient. Going back to step 3 , we realise that the 500ml expiratory air , is 150ml fresh and 350ml alveolar . So this 500ml of **expiratory mixed air** will have the partial pressures of the flowing :

PEO2 = $\frac{150ml \times 150mmHg + 350ml \times 100mmHg}{500ml} = 116mmHg$

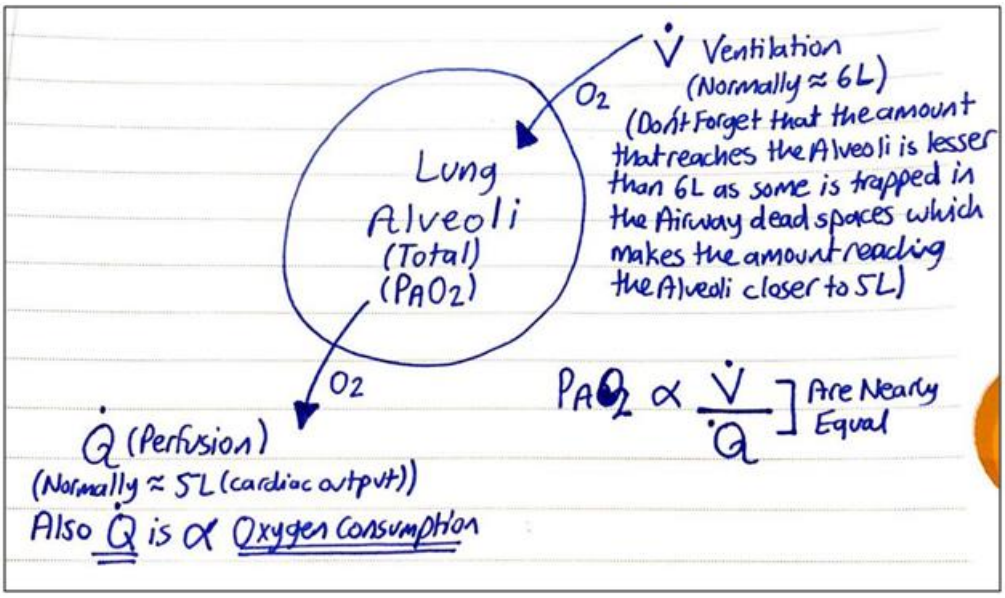
PECO2= $\frac{150ml \times 0mmHg + 350ml \times 40mmHg}{500ml} = 28mmHg$


8
150
NO.
Alveolar Air
Resting
End of Inspiration
1
150
500
7
150
350
150
2
500ml
150
or
6
500
150
3
150
350
150
5
500 ml
150
4
150
End of Expiration

Deep Look : Alveolar air - Systemic arterial blood Equilibrium

Extra Note : Remember that equilibrium in chemistry does not mean equal concentrations ! **It means that the concentrations in a system are Constant , forward and reverse reactions occur at equal rates .**

Why does the Equilibrium Exist ? This question is the same as saying why is the Alveolar PO2 Constant at 100mmHg ? We just said that to have constant concentrations , the reactions in the system should occur at equal rates :



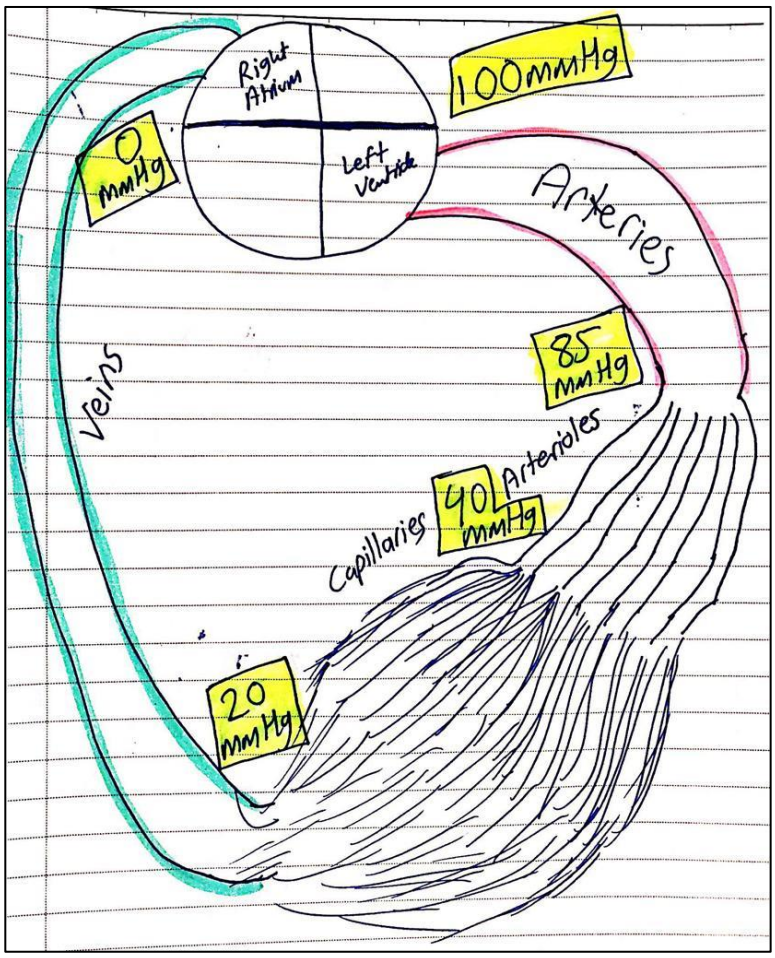
Notice That Alveolar PO2 increases with ventilation (as we breath more , more oxygen is delivered to alveoli - each Liter of fresh air carries 210 ml of oxygen) And PO2 decreases with Perfusion (as blood is delivered to alveoli , it takes O2 and gets saturated , nearly each liter of blood with 200ml of oxygen) , so with Ventilation and Perfusion being around 5 liters , oxygen leaving and entering the alveoli is nearly equal , keeping Alveolar PO2 nearly constant at 100mmHg .

What about during exercise ? Well both Ventilation (V̇) and Perfusion (Q̇ - Cardiac Output) Increase , keeping Alveolar PO2 nearly constant .

Also Remember that Perfusion (Q̇) = Cardiac Output= Venous return which is related to oxygen consumption (V̇O2) , so we can also say that the V̇/V̇O2 ratio is kept constant (as Q̇ α V̇O2).

Deep Look : Measuring Vascular Resistance

Resistance is vague , can be directly measured in the lab , but can't be measured directly in our body , so instead , we *indirectly measure* resistance through the idea that the higher the resistance the blood needs to overcome in a vessel, the higher the driving force (difference in pressure) blood needs across that vessel .



So from the image below , the highest pressure difference needed across a vessel is in the arteriole portion (45mmHg) – Highest Resistance , while the lowest pressure difference needed across a vessel is in the Arteries portion (15mmHg)- Least resistance .

Some may think that how come Capillaries have a lesser resistance than arterioles , despite the fact that a capillary has lesser diameter than an arteriole , and we know that $R\ \alpha\ \frac{1}{r^4}$ or $R\ \alpha\ \frac{1}{a^2}$?

The answer for this is that we Never compare a single capillary with a single arteriole , but taking a look at the cross sectional area or diameter of the whole capillary bed and arteriolar bed , we will see that the capillary bed has a larger cross sectional area which means less resistance. (As we can see in the photo).

Thanks for my Friend Jaleel , We are open to any questions or further corrections .

الحمد لله