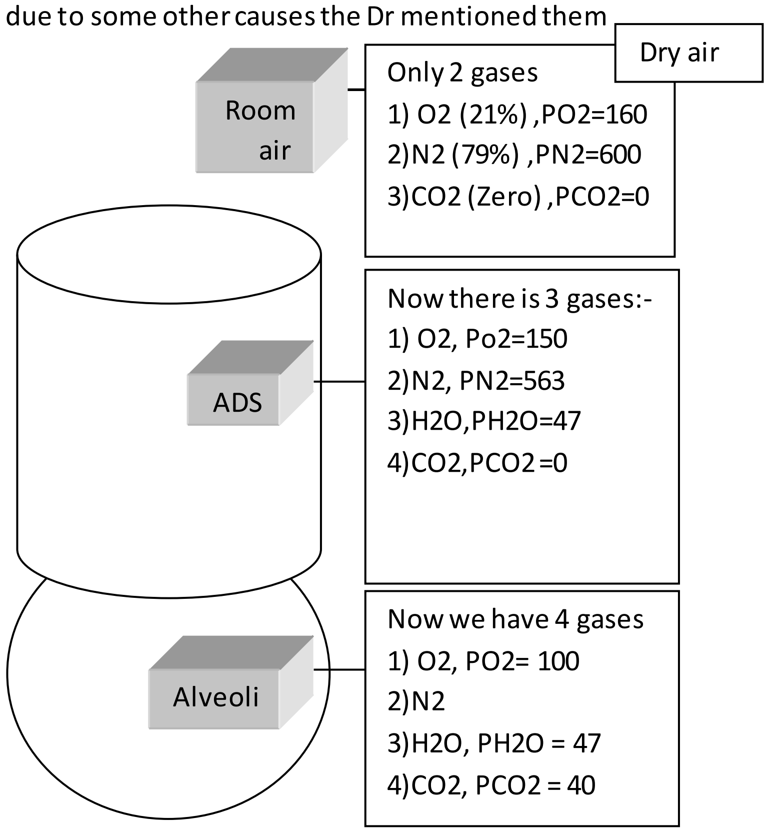
If we want to make sure that Our lungs are working normally, we test blood gases (arterial blood gases) . if ABG'S are normal → lungs will be normal too ,BUT this does not exclude all types of hypoxia because hypoxia can be due to some other causes the Dr mentioned them last lecture. (Ex: Due to the lung itself).



1st we start by analyzing the partial pressure of different gases mainly (O_2, CO_2) in different compartments and said that PO_2 in the outside air (Room air) is 160mmHg assuming it is a dry air Pco_2 is= Zero. Once the air enters the anatomic dead space (ADS) OR (The conducting zone) There is a third gas which is Water Vapor, that is going to displace some of these 2 gases. Water vapor PH_2O always =47mmHg.and what is left 713(79% of this is N_2 , 21% Of this is O_2)

→Therefore the maximum PO_2 we might achieve by inhaling room air in the anatomic dead space is (150mmHg).

→Why 150mmHg ?!

(713 * 21) / 100 = 149,73 =150

→ In the ADS PCO_2 is zero , but when we go down to the lung (alveoli) a 4th gas is added which is CO_2.

In alveoli O_2 is taken by blood that comes from the right heart and going to the left heart so PO_2 decreases and reaches 100mmHg. PCO_2 alveolar is 40mmHg , PH_2O is 47mmHg , the remaining is PN_2.

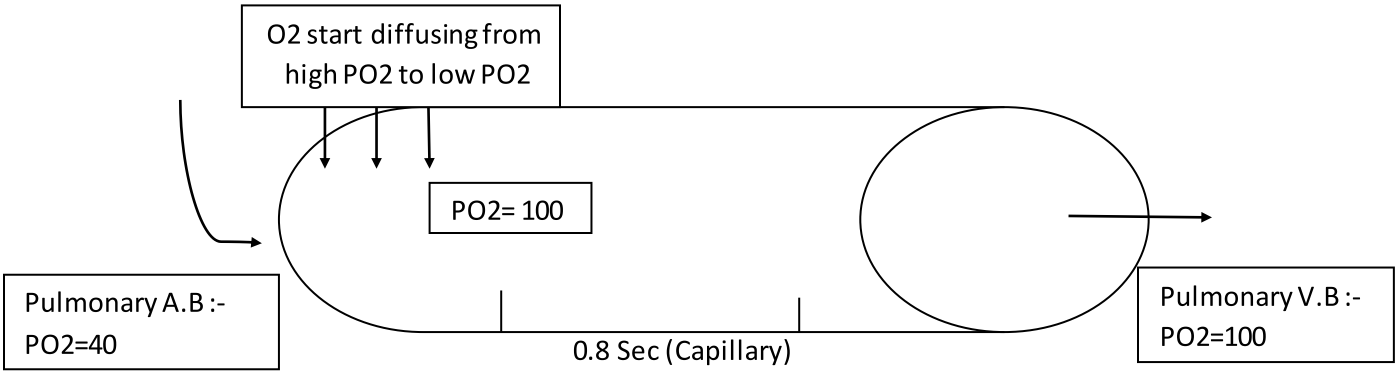
The doctor will not talk about PN_2,PH_2O [because PH_2O is always constant , and N_2 is a spectator molecule]

→ There are 2 purposes for the blood that comes to lung :-

1) it comes to pickup O_2
2) to give up CO_2

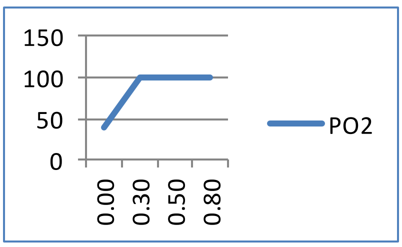
Therefore the blood which is MIXED systemic venous blood ,even though its carried by the pulmonary artery.
Note : (all venous blood is mixed in the right atrium more specifically right ventricle more specifically pulmonary artery).
Blood which enters the pulmonary capillary fill it within 0.8 second which = the cardiac cycle .When the heart rate increases the time of the RBC'S to fill capillary is less than 0.8

Lets say that this figure represent a pulmonary capillary and has 2 ends a venous end and a arterial end :-



Now the venous blood PO2 is 40 mmHg , O2 diffuses only from a high PO2 to Lower PO2 regardless of the other gases like (CO2,….) and that is the concept of partial pressure which is " each gas behave as it is the only gas available in this mixture "
→So O2 start to diffuse , before it reaches 1/3 of the capillary , PO2 totally equilibrates between the alveolar and the blood and PO2 becomes 100mmHg , and the blood continue the other 2/3 without any extra exchange, this means that during exercise when you increase heart rate and decrease cardiac cycle duration , so RBC's might remain in the capillary for 0 .5 second, still 0.5 seconds is more than enough.

To sum up:-
If there is a capillary (pulmonary capillary) there is an arterial end of the capillary and there is a venous end of the capillary, PO2 at the arterial end is 40mmHg , the blood on the arterial end becomes completely equilibrate with O2 before 0.3 second (100mmHg) and continue with no more exchange. That means O2 availability is **NOT DIFFUSION LIMITED** under normal condition. " but it's perfusion limited (from costanzo) " .
(PO2 ALVEOLAR – PO2 ARTERIAL) = ZERO



Note :- That means we are using only 1/3 of the lung , the 2/3 is reserved (used during exercise , destroying in lung tissue due to aging or smoking for example)

But in hypothetical situations like :-
1) heart rate is extremely high 2) we have a problem with the membrane thickening of the respiratory membrane
→Then The blood will leave the capillary without being completely equilibrate by O2, there is some sort of difference , PO2 difference between the alveolar PO2 and blood PO2, we claim in this condition that O2 availability is diffusion limited normally it is not.
(PO2 ALVEOLAR – PO2 ARTERIAL) ≠ ZERO

→ Aging destroys some of the lung tissue but we have reserved tissue

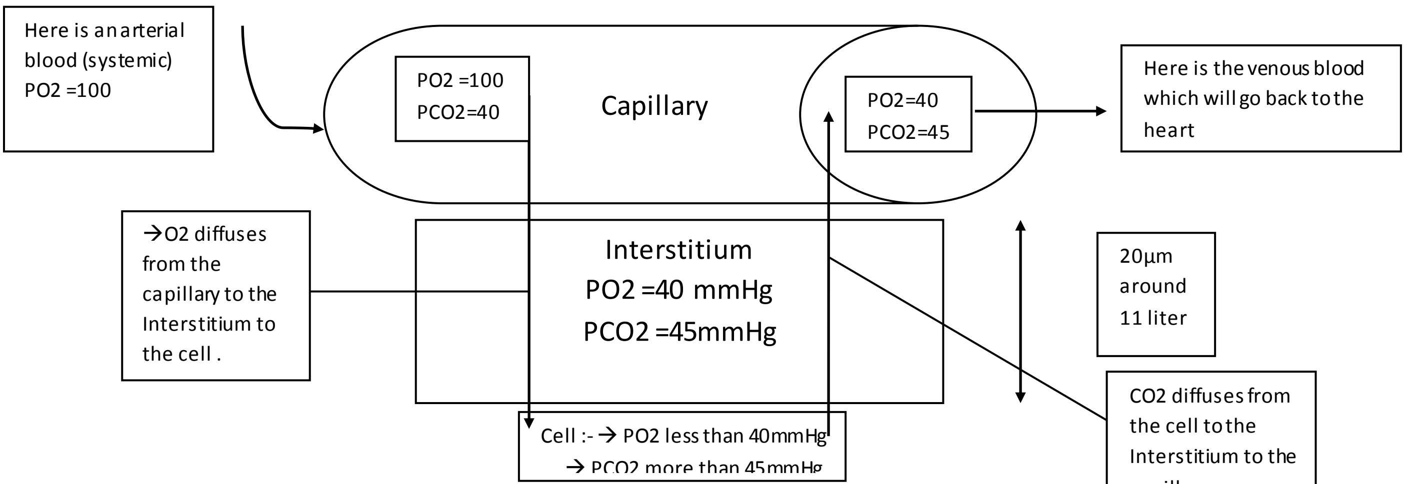
→We want to equilibrate the O2 between the alveoli and the blood. The blood that equilibrates with O2 will go to the left ventricle and pump it to the aorta and continue to the rest of the arteries as 100 mmHg.

PCO2 is 40mmHg in lungs and the coming PCO2 by blood is 45mmHg CO2 diffusibility is 20times more than O2, CO2 Dissolves in water 20 times more than O2 , Solubility of CO2 in water is 20times greater than O2.

If we cross the 1/3 CO2 diffuse to the lungs and PCO2 In the blood becomes 40mmHg.

→ This means in a lung disease (in early stages of the disease) you may see abnormality in the PO2 while the PCO2 is still normal you need too much damage to affect the PCO2 because CO2 has a high diffusibility (20 times more than O2).
So if your ABG'S indicate [low PO2 , High PCO2] it means that more than 90% of the lung has been damaged (we are talking about advance case) "in section 1 recording the Dr said that there will be a problem without any specifications "

Note :- In The heart we will change the numbers of ABG's we are using (PO2 100 / PCO2 40) and we will explain why we are doing this .



Refer to the figure :-
When we come to the tissues there is arterial blood (systemic PO2 100mmHg) and there is a capillary and there is the venous blood which is going back to the heart.
There are cells between the cells and the capillary the "Interstitium" this space is about 20micrometer. There is **NO DIRECT** communication between the cell and the capillary, this space is important, around 11 liters.
As you know total body water equals 60% of your body weight which equals if you where (70kg) [60% * 70 =42 liters]

These 42 liters :-
A) 2/3 of them is intracellular fluid(28 liters)
B) 1/3 of them is extracellular fluid (14 liters)

The 14Liters are subdivided into 2 compartments :-
A) Intravascular (plasma) 3liters .
B) Extravascular (Interstitium) 11 liters.

These 11 liters are subdivided into 2 forms :-
A) 10 liters in gel form .
B) 1 liter is free fluids , we can bring to the vascular system during bleeding.

These information are important and will be explained later .

→ PO2 Interstitium is 40mmHg so O2 diffuses to the Interstitium from the capillary PO2 intracellular is less than 40mmHg "depends on the activity of the cell" so O2 diffuses from the Interstitium to the cell.
→ PCO2 intracellular is more than 45mmHg therefore it diffuses from inside the cell to the Interstitium PCO2 (the PCO2 in the Interstitium is 45mmHg) so CO2 diffuses from the Interstitium to the capillary (as PCO2 is 40mmHg in the capillary) , so the capillary blood will equilibrate with the Interstitium and end up with PO2=40mmHg and PCO2=45mmHg and that is the venous blood which comes back to right heart.

→Now what is the composition of Air in the **expired Air**?!What is the composition of early expired air?!What is the compositions of **mixed expired air**?!
The first part of the expired air is exactly like the atmospheric air but it is humidified atmospheric air because there is water vapor, and therefore PO2 in the expired air -the 1st part- equals 150 and PCO2 equals zero ; the last portion of the expired air is alveolar type of air PO2 = 100 / PCO2 = 40
when you mix them you have to consider the volume from each space .If equal volume then the mixed expired air will be 125 [(150+100)/2]
→But if the volume is <u>not</u> equal each compartment participate according <u>to its volume</u> .

The mixed expired air depends on the volume of the anatomic dead space (ADS) which is around 150ml and the volume of alveolar air at the end of inspiration is more ; at the end of expiration is less, before the tidal volume which equals (500 ml) There are around 2.2 liters in the lungs , At the end of tidal volume there will be 2.7 liters.

so when we exhale; we exhale 150ml from the ADS and 350ml from the alveolar air so we might think that In the mixed expired air the PO2 will be closer to the alveolar air rather than ADS because of the double or more than double volume

PO2 in the mixed expired air is equal to :- [150*150 + 350*100]/500 =116

PCO2 in the mixed expired air is equal to :- [150*0 + 350*40]/500 = 28

*Note: the equation in the box applies also for PCO2 .

$$\frac{\underset{\text{ADS}}{\text{Volume}^*\text{PO2}} + \underset{\text{Alveoli}}{\text{Volume}^*\text{PO2}}}{\text{Tidal volume}}$$

It is very important to know the composition of the expired air because the purpose of the respiratory system is 2 things :-

1) deliver air (ventilation) 2) to deliver Blood (perfusion)

→if you have ventilation without perfusion this is wasted ventilation you waste your effort

→If you have perfusion without ventilation you are wasting your perfusion

The heart as we know can control this ,the heart does not send blood to an area which does not contain O2 , <u>hypoxia is a major vasodilator in the systemic arteries</u>. But in the lung its is vasoconstrictor if you don't have O2 then you constrict the arteries then you shift the blood an area with more O2 { why should I send blood to an area that does not have oxygen }

NOTE :-the hypoxia has 2 different responses on the arteries as we know from our cardio vascular system.

Therefore if one area of the lung (assuming it is the apex) is ventilated but slightly perfused because of the gravity , then the air which comes out from that area is like the air in the ADS has no chance for exchange and therefore by analyzing the expiratory air you can know if we wasted volume or not .

1st you measure the anatomic dead space volume, we have methods and we will learn how to do this

2nd we measure if we have wasted volume

now to sum up:-

→What is the tidal volume?!

The tidal volume (TV) is the volume we inhale or exhale each breath which is 500 ml .

Tidal volume is divided into 2 volumes:-

1) 150 ml anatomic dead space volume

2) 350 ml the alveolar volume which is subdivided into :-

1)alveolar ventilation

2) alveolar wasted volume→this part is present when you have an area of the lung that is ventilated but not perfused.

→ For example there is an area which have ventilation/perfusion (V/Q) ratio = infinity
here the ventilation is high and the perfusion is zero .

Normal people have zero wasted volume .

so we have a new concept which is
physiological dead space: is equal to anatomic dead space + alveolar wasted volume
in normal people the alveolar wasted volume is zero and therefore the anatomic dead space equals to the physiological dead space , But if the alveolar wasted volume is more than zero physiological dead space become more than anatomical dead space .

→ NOTE (1) :The anatomic dead space volume can't be higher than physiological dead space
→NOTE(2): the physiological dead space volume is larger than the anatomic dead space that means that there is an abnormality

now we want to see how we measure the anatomic dead space:-
if we take a single breath what type of air do we have in the ADS ?!
We have O_2,N_2,H_2O and there is no CO_2
in the lung we have all of them

now if we analyze the CO_2 in the exhaled air here we have 3 zones :
1) alveolar
2) anatomic dead space
3) transitional zone →" which is between the 2 zones "
→ because there is diffusion of gases this zone indicates that the presence of CO_2 is **gradual**
if we analyze the expired air the CO_2 in the expired air :- we should expect up to 150 ml CO_2 to remain zero (in the anatomic dead space) all of sudden it becomes like 40mmhg but because there is a transitional zone we see gradual appearance of the CO_2 and That's how you analyze the anatomic dead space .

<u>now how you analyze the physiological dead space :-</u>

now the arterial blood PCO_2 is 40mmHg and the alveolar PCO_2 is 40mmHg
→arterial always equals the alveolar
but the in the mixed expired air the PCO_2 is defiantly less than 40mmHg

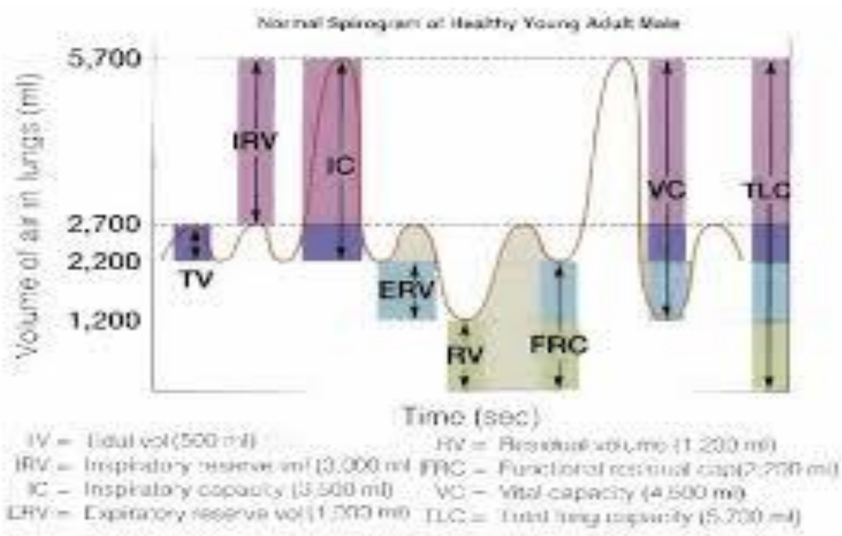
Now to know if there is wasted volume or not we use this equation :-

$$\frac{(anatomic\ dead\ space\ volume\ )}{(Tidal\ volume)} = \frac{(PCO2\ arterial - PCO2\ Mixed\ expired\ air)}{PCO2\ arterial}$$

anatomic dead space volume / 500 = (40-28)/40
ADSV/500 = 12/40 → ADVS= 150ml
by this equation we use it to know if there is a wasted volume or not

Ex : if the result was 170ml and the ideal 150ml that means that you have 20ml wasted volume

Now before we start with the physiology of the respiratory system we have to know the volumes and capacities in the lungs :-



1st Before we take the tidal volume there is 2.2 liters inside the lungs when we take the tidal volume it becomes 2.7liters
→ now on top of the tidal volume we can use our inspiratory muscles ,all muscles, to induce a maximal inspiration (forced inspiration) we can add 3 additional liters reaching 5.7 liters so these extra 3 liters are called inspiratory reserved volume(IRV) , normally we don't use it unless we are in exercise or voluntary inspiration .
Now what is the IRV : it is the volume of air you can inhale forcefully on top of tidal volume now you go back and breath normally , Now before you take your tidal volume you can use your expiratory muscles to exhale forcefully half of the 2.2 which is 1.1 , this 1.1 is the expiratory reserved volume.
Some volume remains in the lungs even if you try to exhale it we call it residual volume " we can't empty our lungs "

so far we have mentioned 4 volumes :-
1)TV 2) IRV
3)ERV 4)RV

→Note :- we can't empty our lungs

Now if we add 2 volumes together we will come up with a new volume this new volume we don't call it volume anymore we call it Capacity therefore pulmonary capacity is when you

add 2 volumes or 3 volumes or maximally 4 volumes
→ So you will end up with 4 capacities :-

1) inspiratory capacity 2) functional reserved capacity
3) Total lung capacity 4) Vital capacity

1st) capacity is by having the tidal volume and the IRV we call it **Inspiratory Capacity**

2nd) The most important capacity is **functional residual capacity** (FRC) which is the volume of air present in the lungs before we take the tidal volume equals 2.2Liters = ERV + RV
→" this is the most important one we will use it in every single lecture "

3rd) → Now am going to ask you to inhale deeply / forcefully /maximally you will reach up to 5.7 Liters

→And from this point am going to ask you again to exhale forcefully empty your lungs as much as u can how many volumes you are going to exhale ?! 3 volumes
1) IRV 2) TV 3) ERV
These 3 together are called **Vital capacity**
Vital capacity :- which is the volume of air we can exhale forcefully following forced inspiration is the (IRV +TV+ERV)

→Now if we take the 4 volumes we will have **Total lung capacity (TLC)**
which is the maximum volume of air both lungs can take 4 volumes

There is 1 volumes left :-
if we take the lungs outside the body they will collapse totally up to 150 ml the , the lung inside the body surrounded be a negative pressure and therefore they can't collapse totally ,there is some kind of force pulling the lung outward so they can't collapse totally .

→So if this negative pressure is removed this means that the lung will collapse totally and there will be 150 ml in them this is called **minimal volume**

So what is the minimal volume?!
it is the volume presents in the lungs after they collapse
"logically we have to say that in lungs the volume must be zero not 150 ml "
the DR call it the resting volume of the lungs the volume of the lungs when the lungs no more tending to collapse there is no forces out or in applying to the lungs .

→Now if we are talking about a rubber band
the rubber band has a resting length but when we stretch it, it has a recoil tendency it will

recoil back to its resting length.
resting length means that the rubber band loses it tendency to recoil back.

→ resting volume of the lungs → means that the lungs lose its tendency to collapse

Which means in vivo inside the thorax the lung even at the residual volume still trying to collapse but there must be a type of expanding force that prevent this collapse (negative pressure)

Why minimal volume of the lungs is important ?!
Sometimes we may face some situations when there is child who was born dead he had not taken any single breath So if we take his lungs and put them in water they will sink down but If he took a breath, lungs would stay on the surface of water and that means that he was born alive and then died finally the case will be given to the forensic medicine.

Question : if you have been given a balloon what is the hardest stage in filling it ?!
→ The beginning
If am going to inflate a totally collapse balloon ,I have to apply a pressure,

But at the beginning I have to apply to much pressure before I have little a change in the balloon but at certain point little force is enough.
(we just put little force) little force In lungs means little contraction of muscles .
Why do we need to contract our respiratory muscles ?! for inhalation → for O_2 → and O_2 for ATP .
Our respiratory muscles utilize less than 5% of the total O_2 consumption OR less than 5% of the total ATP leaving 95% to rest of the body. This means it is very efficient machine takes for itself only 5% and give you 95 %
But if you have to put too much effort then these muscles might reach 20% or for sometimes 80% so when you reach this level then only 20% will be used by the body and ultimately ,you will die from fatigue (one of its causes unavailability of ATP)

So our respiratory muscles utilize less than 5% of total ATP/O_2. So if you are facing any problem this means that you will start utilizing more than this 5%.

We are breathing from the FRC it is much better to inflate a partially inflated balloon rather than inflating a totally collapsed balloon where you put to much effort (means too much ATP) to inflate it .

Done By : Faris khamaiseh ☺