# Diffusion Confusion

By John R. Goodman BS RRT

(Dedicated to my good friend Lyn Cole)

In previous articles I have written about the delivery of oxygen into the lungs, and the way the lungs eliminate carbon dioxide as it accumulates. You can mentally picture your respiratory system as a small escalator in which oxygen molecules are constantly moving down and carbon dioxide molecules are constantly moving up. If all is well, this goes on automatically (without thinking) every breath we take. But what happens at the bottom of the escalator? This is where the action really takes place. The newly arriving oxygen molecules must travel across a very short distance so they can catch the express subway moving very quickly by. In this case it is blood flow (capillary network) moving in and around the terminal units of the lung called alveoli. So this analogy may help you understand better what is normally happening.

$O_2$ in, $CO_2$ out

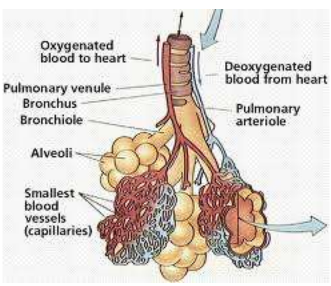
Lots of molecular movement

Capillaries waiting to take on oxygen

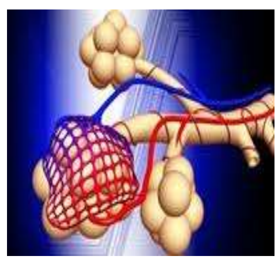
Gets a little tight but the $O_2$ gets delivered

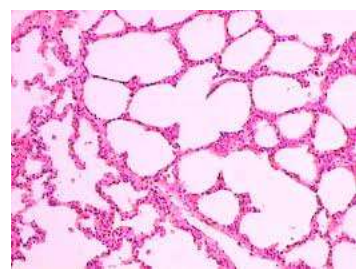
If the capillary network can be thought of as the "subway system" than the oxygen molecules must not only get on the subway, but must do so quickly. Once inside the capillary, the oxygen molecule must latch on to a passenger already on the subway. The other passenger would be a Hemoglobin molecule found inside the red blood cell (RBC). This must happen very quickly as the red blood cell carrying the hemoglobin is only passing by for ¾ of a second. In fact most of the diffusion of oxygen takes place in the first 1/4 of a second of transit time. In this way the majority of our oxygen is transported by the Hemoglobin throughout the body to be used for all intracellular functions. In review, remember that one of the byproducts of all this cellular activity is carbon dioxide. And it is this carbon dioxide that must be eliminated by the lungs. While the oxygen molecules are charging into the capillaries, carbon dioxide molecules are doing the exact opposite. They are moving from within the capillaries out into the terminal, and taking the escalator up and out of the body as exhaled air. They are in effect getting off the subway, up the escalator and out into the fresh air….where they are then cycled back into use by plants for photosynthesis etc.

What actually moves these molecules up and down the escalator is basic chemistry in action. For a molecule to move across any membrane, there have to be more molecules on one side of the membrane than the other. The side with more molecules will exert a greater pressure than the other side, and so pressures on both side of the membrane will equilibrate or equal each other. This is called a pressure gradient, and it just means that molecules always move from areas of higher concentration to those with lower concentrations. The membrane we are talking about here is the alveolar-capillary membrane and we just usually called it the AC membrane or unit. Since there are about 300,000,000 million alveoli in the adult lung, and even *more* capillaries it has become very convenient to just show one AC unit to represent what is happening in them all.



Anatomy of AC membrane

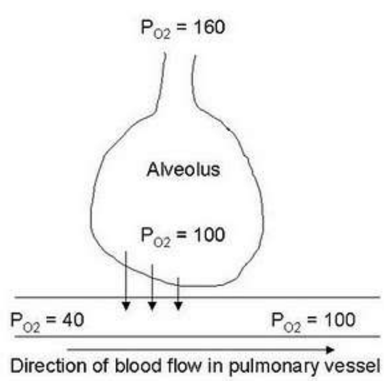

Alveoli are actually bathed in capillary blood flow

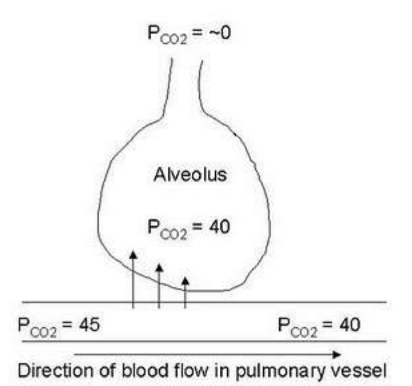

Normal alveoli Magnified 100X

There are a number of straightforward equations that show how much oxygen gets into the lungs from the air we breathe. Not talking about saturation here, because our oxygen is not yet in the blood. That's why it is spoken of in terms of the pressure it exerts. At sea level this is just about 160mm Hg. By the time we subtract the pressure of water vapor (47 mm) and a few other entities, the pressure of oxygen in the alveoli is about 100mm Hg. That's a pretty decent starting pressure. Remember that the capillaries in the lung are bringing back all the blood that has already given off its oxygen, the pressure of oxygen is therefore down around 40mmHg. Simple math shows us that there is a 60mm difference (100-40) between the two values.  This is the "pressure gradient" I spoke of earlier.  Oxygen therefore quickly moves across the AC membrane and into the capillary.

The flipside of the equation works much the same way, only with lower pressures. The blood in the capillaries coming back to the lungs has picked up all the carbon dioxide ($CO_2$) that is produced by the body minute to minute.  The pressure it exerts is about 45mm Hg.  The pressure of $CO_2$ in the alveoli is just a little lower at around 40mmHg.  But carbon dioxide is super soluble in the watery part of the AC membrane and so even though the pressure gradient isn't that large, (5 mm) it also very quickly gets off the subway and takes the escalator out of the body. This of course assumes that all the components of our respiratory system are intact and functioning optimally.  That includes everything from our nose all the way down to the millions of alveoli working together on every breath.

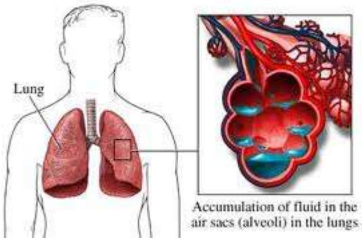
Diagrammatically the exchange of oxygen and carbon dioxide might look something like this:



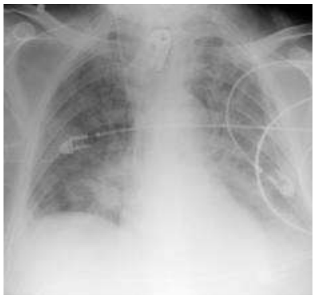



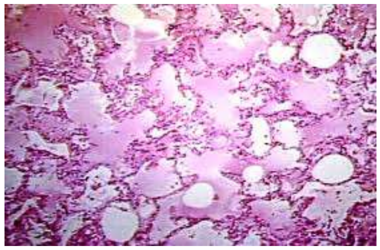

If you look at the values for the $PO_2$ and $PCO_2$ in the outgoing blood you can see they are "textbook" normals.  In reality the normal values range from about 80-100 mm Hg for the $PO_2$ and 40-45mm Hg for the $PCO_2$.  Even in our very simplistic diagram it can be seen that anything that prevents oxygen molecules from getting from the alveoli, across the components of the AC membrane, and down to the capillary will by necessity lower the amount of oxygen that eventually gets into the blood.  What a journey that oxygen molecule must make! Oxygen molecules must first diffuse through the cell wall of the alveoli itself, move through the space between the alveoli and capillary, and then power its way through the cell wall of the capillary on its way to finding a red blood cell containing the all important Hemoglobin protein with which it must combine.

So what would be a good example of a condition that could cause a decrease in the diffusion of oxygen? How about something as common as pulmonary edema or fluid in the lungs?



Fluid blocking the AC membrane


CXR with pulmonary edema a "whiteout"


Alveoli filled with frothy pulmonary edema fluid

Beyond these "physical" barriers to oxygen diffusion, there is the actual destruction of the AC membrane as commonly seen with COPD and so many other diseases. Unfortunately, when you close the terminal (alveoli) you also close the subway (capillary.) And with COPD unfortunately, once you close the station, it *stays* closed. In the pulmonary function lab, it is pretty easy to measure how well you are diffusing oxygen into your blood. We call this the Diffusion Capacity of the Lung for Oxygen and it is usually abbreviated as DLCO. Notice what is missing here? It's the "2" from $0_2$. That's because in the most common DLCO study we use the gas Carbon Monoxide or CO. Although there are three ways this test can be performed, the most common study is done is the "Single Breath Test."

In this very simple test the patient breathes naturally for a few breaths, then exhales as much air as they can, and then takes in the biggest breath they can and they hold that breath for 10 seconds. The taking of the deep breath coincides with the administration of a fraction (.3%) of the gas carbon monoxide. Carbon Monoxide is used because it will combine with your Hemoglobin 210 times stronger than oxygen. It literally flies across the AC membrane. Once you exhale, the computer makes the calculations and essentially prints out your diffusing capacity in the following units…ml/min/mm. For example, a normal diffusing capacity is somewhere around 25ml/min/mm. Let's take this a little further. Remember from our diagram above the pressure of oxygen in the arterial blood is given normally as around 100mm Hg. So…25mls x 100mm = 250ml of oxygen diffusing into the blood *every minute.* Well what do you know…the normal oxygen consumption of the body is 250ml/min!


RT and patient performing DLCO testing

Patient takes a deep breath and holds it for 10 seconds

Diffusion studies are normally part of a complete pulmonary function study. So, just the same as with your flow rates, your test results are printed out as both the actual value or number….and the percent of predicted value. Predicted values are based on your age, height, and gender. "Experts" from around the world have tested thousands of men and women of all ages and heights. Many times they use the military to gain this information. Once smoking is ruled out, it is pretty safe to make assumptions on normal values for patients from the age of about 20 up to 90 and from as short as 4 ft 8 inches to 6 ft 8 inches tall.

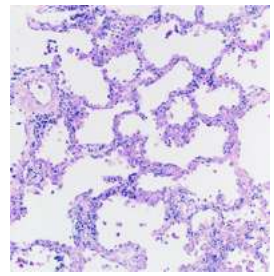
Once your height, age, and gender are plugged in to the pulmonary function device, the calculation of how you did compared to the known normal values give us a simple percentage. The normal range for DLCO is usually given as 75%-125% of predicted. Some physiologists believe the range should be always greater than 60% but less than 120%. Yes, you could be super normal if say, you are polycythemic and have very high Hemoglobin. Generally speaking your DLCO will be decreased with any of the lung diseases that either prevent oxygen from easily moving from the alveoli into the capillary (increased distance to travel) or disease that results in destruction of significant amounts of functioning lung tissue (loss of surface area available for diffusion). DLCO is inversely related to age, so the value decreases as we get older. This makes sense as we all lose functioning lung tissue to the normal aging process.

Interstitial lung disease from any cause will result in scaring of the lung tissue between the alveoli and capillary. Not only is the distance increased, but scar tissue is also very tough tissue. It almost doesn't matter how many oxygen molecules are in the alveoli, they just have a very hard time getting though that barrier.

It’s like trying to break through these brick walls and when an oxygen molecule finally does get through, it has to deal with the changes in the lung itself.


Very hard to get across


Long way to go


No help once there

Emphysema is the most common cause of decreased DLCO due to destruction of functioning lung tissue.  As the disease progresses there is are simply fewer and fewer alveolar/capillary units available for oxygen to diffuse into.  Interestingly, patients with neuromuscular disease or skeletal deformities usually have normal diffusion capacity values.

Hopefully by now some of the “diffusion confusion” has been cleared up for you.  It should be clear that the diffusion capacity can be affected by many factors such as abnormal hemoglobin in the blood, carbon monoxide, and even anemia.  For these and other reasons the DLCO is viewed as an **important**, but yet singular test.  It is only when your pulmonologist puts this value in the context of your flow rates and lung volumes that he/she is able to rule out or rule in a disease or condition.

There is still blood to give, X-rays to have, 6 minute walks to take, and of course the history and physical your doctor gets by examining and interviewing you as a patient.  The numbers only tell part of the story.  There are patients who have fairly normal pulmonary function values, but a very low diffusion capacity.  These patients are medical “enigmas.”  Sometimes we find out what’s going on, sometimes we don’t.  But, you can’t put the whole puzzle together to see what the picture is without every last piece…. right?