

Spirometry Geometry

By John R. Goodman BS RRT

Dedicated to my good friend, Dr. Richard Harris

If all patients with lung disease can be thought of as sort of a jig saw puzzle with many pieces, than surely pulmonary function tests (PFT's) are one of the most important pieces. Yes the blood gases are important. Yes, a complete history and physical is important, as is all the other lab work ordered by your physician. Your physician probably has ordered a standard chest x-ray, CAT scan, and maybe even an MRI. Each of these is also important pieces of the patient picture. So where do pulmonary function tests fit in? Well, as always it is best to start at the beginning. (I won't be covering diffusion in this month's discussion of PFT's. Please refer to "Diffusion Confusion" for much a more detailed explanation)

Although physicians such as Galen of Pergamum made early attempts to measure air moving in and out of the lungs before 200 A.D., it would be many centuries before any accurate measure of lung volumes were possible. As was the case in many pulmonary "firsts", the technology had to be invented first in order to perform the test. That is why we jump all the way up until the mid 1840's for the next major advancement, and as always there is an interesting story attached.



Galen of Pergamum



John Hutchinson



Hutchinson's Spirometer

John Hutchinson was an English surgeon who is given universal credit for inventing the first accurate spirometer in 1846. Hutchinson was doing some work for an insurance company and was convinced that measuring the "vital capacity" of individuals would yield information to help predict mortality. If you think about it, he even coined the term "vital capacity" for this very reason. A term still used today, every day thousands of times around the world. He also knew enough about statistics to know he had to measure many people of all ages and sizes to come up

with some predicted normal values. To that fact he performed (by himself) spirometric tests on over 4,000 subjects before he published his work. He even figured out that he would only record the best of 3 efforts to take into account the learning effect.



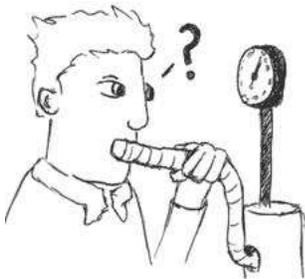
“Duke of Durham”
First commercially available
pack of cigarettes (1892)

Another interesting historical note concerns the fact that probably not even one of his test subjects was a cigarette smoker. Oh they may have occasionally put some tobacco in a pipe, rolled their own, or stuck a chew in the mouth, but it wasn't until 1881 that the first automated cigarette making machine was invented, and not until 1892 before they were packaged and sold almost like today. In 1892 around 1,000,000 cigarettes were sold, and it only took 5 years to reach the billion mark.

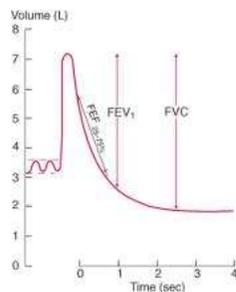
The main pulmonary diseases of Hutchinson's day were Black Lung disease from coal mining, Tuberculosis and Pneumonia. Oddly, the invention of the spirometer was not widely accepted in London, or anywhere else for that matter. In fact, it wasn't until about 40 years ago, that a major effort was initiated by Dr. Tom Petty to get basic spirometers in the offices of family practice physicians. So, in pulmonary diagnostics the greatest debt is owed to Dr. Hutchinson and his wonderful Spirometer that allows us to measure our vital capacity (VC). Since patients are heartily encouraged by their pulmonary function technician to empty their lungs as hard, as far, and as fast as they can, we call it the FVC for forced vital capacity.

As important as it is to know an individual's FVC, it is equally important to know how *fast* a patient can exhale all the air from their lungs especially in the first second of exhalation. This is known as the FEV₁ or forced expiratory volume in one second. It wasn't added to pulmonary testing function until 1947! These two measurements alone, and the ratio between them (FEV₁/FVC) gives the physician a great deal of information. Normal lungs empty completely in 6 seconds or less.

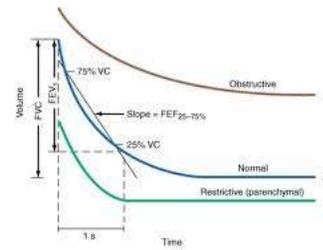
For that reason many PFT's now report FEV at both the 3rd and 6th second, as it is sometimes an easier test for patients to perform. Collectively, measuring both the volume of air in the lungs, and how quickly the lungs can be emptied gives us an approximation of lung mechanics. The results of your efforts are graphically shown a number of ways, but we'll stick with the very basic tracing for teaching purposes. So what does a normal "spirogram" look like?



"Blow, blow, blow..."



Normal Spirogram



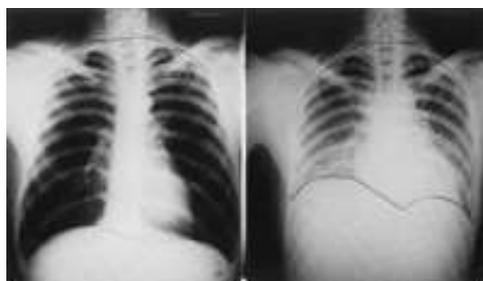
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Normal vs. Obstructive vs. Restrictive

Let's just focus on the flow curves themselves. Blowing into the spirometer as hard, far, and fast as you can gives us both the total amount of air you can blow out (FVC) and that total amount over time in seconds (FEV₁ etc). In the normal spirogram above, the patient managed to blow out about 5 liters of air (FVC) and got 4 of those liters out in the first second (FEV₁). Right here is where we can begin to thank Dr. Hutchinson for his dedication to statistics in coming up with normal values. Not that many years ago pulmonary function techs actually had to use a pencil and ruler to measure these figures off standard graph paper. And then, had to go to an actual table of normals to compare their patient's efforts to known normals. Of course, these days all of this information is integrated into the software of very sophisticated pulmonary function equipment. Not only is all of the testing automated, but many of the programs even do interpretations of the numbers generated.

However, in our normal patient above if we put the 4 liter FEV₁ over the FVC of 5 liters per minute, we get 4/5 or 80%. And what do you know, this is perfectly normal. In fact, pulmonary function values of 80-120% of predicted would be considered normal. Look closely at the curves in the last graphic above. You can clearly see the very different curves associated with both obstructive and restrictive disease. Prolonged expiratory times are the rule with obstructive lung disease, and very, very short expiratory times are associated with pure restrictive disease. Is this diagnostic by itself? Of course not, but it adds significantly to our patient picture puzzle. Changes in both the absolute values for FEV₁ and FVC give us a great deal of information *as do* changes in their ratio. So rather than go into detail

on a description of all the other values we measure during a PFT, we're going to concentrate on the *purpose* of doing PFT's. In addition to measuring how much air can be moved in and out of the lungs, and how fast we can get it out, we can also see how "stiff" the lungs and chest wall may be. Diseases associated with restriction of lung expansion or skeletal deformities decrease the amount of air that can be inhaled. If you get less air in...you certainly get less air out. Look at the picture below. On the left is a CXR of a patient who has taken in the deepest breath they could. Remember on a CXR air shows up as black. You can see how far down the diaphragm has dropped the base of both the left and right lung. Contrast that with the lungs after full exhalation. You see much less air (**black**) and the diaphragm has moved way up into the chest cavity to assist with the forceful exhalation.



Lungs after Full inspiration Lungs after Full exhalation

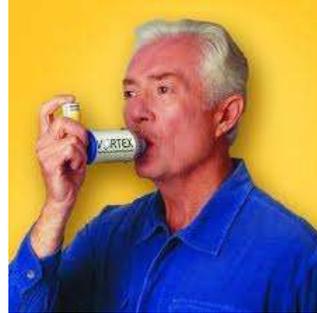
Pulmonary function tests are not just used to screen for the presence of obstructive or restrictive disease. PFT's are commonly done before surgery, especially big surgery such as an abdominal or thoracic operation. The surgeon needs to know not only that the patient has lung disease, but how bad it is. If the patient is morbidly obese PFT's are very important indicators of how the patient will do after surgery. PFT's will also be helpful if it is known in advance that the patient will be under general anesthesia for a lengthy period of time. It was realized very early that spirometry was also an excellent way to follow the course and progression of many chronic pulmonary diseases.

Pre-surgical PFT's make sense as the FVC measurement reflects the patient's ability to take a deep breath, cough, and to keep their airways clear of secretions after surgery. It can even help determine how easily a patient can be weaned from a ventilator should that be necessary. And finally, PFT's can be used to judge the efficacy of various pulmonary medications prescribed by the physician. Many pulmonary patients know that it may take a few different bronchodilators to get the best effect on their breathing, with lowest number of side effects. Repeat PFT's help fine-tune this process. This is why virtually every PFT performed, will be

repeated following the administration of a known fast acting bronchodilator. If there is a 10-15% increase in your volume or flow rate, it is considered a true bronchodilator effect.



You'll blow.. blow... blow...



Take a couple of puffs of a bronchodilator...



The PF tech will print out the results

Hutchinson's normal values for vital capacity were based (rightly so) on the height, age, and of course sex of his test subject. Today, over 150 years since Hutchinson first published, we now know that race can also make a difference in PFT values. It's possible the difference in trunk length relative to the standing height, fat free mass, strength of the respiratory muscles and even the dimensions of the chest may combine to affect values. African Americans, Hispanics, Asians, and even Native Americans therefore have their own race-specific table of normals.

What are some examples of the diseases or conditions that show obstructed airways?

1. Anything that causes the small airways (usually less than 1-2 mm in diameter) to constrict due to smooth muscle contraction such as asthma.
2. Anything that causes the airways to narrow such as inflammation and swelling of the small airways such as we see with Chronic Bronchitis.
3. Anything that physically blocks the small airways such as excess mucus, or perhaps a tumor that has grown into the airways.
4. Disease that actually destroys functioning lung tissue with loss of the "tethering" effect normally found in the lungs. Emphysema is clearly the most common disease in this group.



Normal Chest X-Ray



CXR Emphysema

Actually, the list of diseases that cause obstruction to show on PFT's is not a very long list. You might be quite surprised to see the difference when we look at restrictive diseases and disorders. These would include:

1. Some pulmonary diseases actually affect the lung tissue BETWEEN the airways, many times resulting in the development of scar tissue. This would include diseases like Sarcoidosis, Tuberculosis, and Pneumonia.
2. Some restrictive patterns show up on PFT's due to disorders outside the lungs themselves. Skeletal disorders such as or Kyphosis or Scoliosis will restrict how well the rib cage can expand. Fluid outside the lungs, but inside the ribcage called a Pleural Effusion will make it very difficult for the lungs to expand fully. Something easy to overlook is a normal pregnancy. As the baby continues to develop, he/she pushes the diaphragm up making it difficult for mom to take in a deep breath. And finally, patients that are morbidly obese will have great difficulty taking in a deep breath as there is just too much weight to move for the diaphragm to drop properly. Lastly restrictive PFT's are seen if there is fluid in the abdominal cavity from infection, certain large tumors, and something as simple as pain on inspiration such as may be seen with a broken rib, or even pleurisy will produce a restrictive defect that will show up on the PFT.



CXR Sarcoidosis



CXR Tuberculosis



CXR Kyphoscoliosis

3. The last group of restrictive pulmonary function patterns is seen with any disease or condition that affects the neuromuscular system. This would include situations where the diaphragm is paralyzed. This may be due to trauma or accidental bruising of the nerves that control the diaphragm during certain surgical procedures. There are also true neuromuscular diseases such as Muscular Dystrophy, and Myasthenia Gravis that cause great muscle weakness and fatigue. Although Polio has been almost completely eliminated from the entire world, it is still found in Nigeria, Pakistan and

Afghanistan, and so cannot be excluded from this list. And it would go without saying that any patient with Lou Gehrig’s disease would surely produce a restrictive PFT result.

The above listing of diseases, disorders, or conditions that have profound effects on pulmonary function tests, is by no means complete. But it should give you a pretty good idea of just how far we have come since Dr. Hutchinson invented his most wonderful apparatus just to measure the “vital capacity.” I would be remiss however, if I didn’t mention one more time the tireless work of Dr. Tom Petty trying to get basic spirometry recognized and more widely utilized to recognize disease patterns much earlier than had been done in the past. Dr. Tom was famous for telling his patients to “Know Your Numbers.” And so it is nice to know the technology for patients to both measure and know their numbers at home has been available for over 20 years. We have gone from Dr. Hutchinson’s original spirometer that was actually about as tall as the patient, down to very small, inexpensive, but very accurate hand held spirometers.

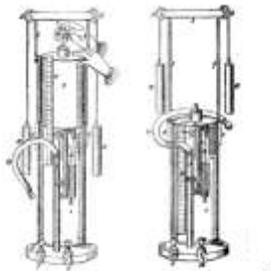


Figure 4. Hutchinson's spirometer¹

Patient actually had to stand To perform test to determine Vital Capacity test



There are many hand-held spirometers available today



Portable, accurate and costs less than \$70.00

Way back in 1597 Sir Francis Bacon (a renaissance man in his own right) said “Knowledge is power.” You can literally hold that power in the palm of your hand. Take advantage of the technology to monitor your disease at home. Combine your spirometer with your oximeter and “KNOW YOUR NUMBERS!” Sir Francis Bacon would be proud of you.

