

PULMONARY FUNCTION TESTING



SPIROMETRY - *The Most Important Test in our Pulmonary Function Arsenal*

by Jim Harvey MS, RPFT, RCP

By far the most commonly used, important, and accurate test in our pulmonary function testing arsenal is the composite of tests we refer to as "spirometry". I know that all of you are very familiar with this topic but consider reading on for an alternative and hopefully fresh view. Part I will cover the meaning of spirometry, the structure of the test, diagnostic indications, and variant procedures. Part II will cover equipment, testing techniques, and standards of calibration and quality assurance. At first glance, spirometry appears to be a simple and easy single test, but we all should be familiar with its complexity.

The word "spiro" in spirometry is from classical Greek on two levels. On one level it is from the word to breathe as in "inspire" or "expire". For example, the word "conspire" literally means to breathe quietly or whisper in secret together. On a more basic level the word "spiro" is also the Greek root indicating fire. The ancient Greeks believed that we brought air in and out of our mouths which

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was used to support a fire inside of us which gave us life and strength, so that breathing was the breath of life. We know that the Greeks were absolutely correct about our breathing supporting life since our inhaled oxygen is used to support aerobic metabolism.

The diagnostic spirometer was invented by John Hutchison, an English physician, in 1849. His original invention is not so much different from water seal spirometers of today, or shall we say, from a few years ago since they are no longer produced as far as I know. John Hutchison also described the major lung volumes and capacities as we now know them and performed extensive spirometry on coal miners in North England, and advocated for the protection of miners against the damage from dust inhalation.

Simple spirometry includes forced vital capacity (FVC), graphed as either a time-volume curve or as a flow-volume loop, slow vital capacity (SVC), and maximum voluntary ventilation (MVV). The flow volume loop is the most useful and most commonly used. It is a wonder that by just glancing at a flow-volume loop, for example, without reading the numbers, we can ascertain so much information about a patient's lung function: restriction versus obstruction and degree, response to bronchodilator, fixed versus variable extra thoracic airway obstruction, patient effort and

consistency, indication of sleep apnea, indication of lung rejection, and lung hyper reactivity. We attach a patient to a mouthpiece and have them take a deep breath in and out and by looking at the graph of flow on the Y axis and volume on the X axis, we in essence, see a "picture" of lung function. As we all know, this picture is as distinctive as a finger print, with no two individuals having exactly the same flow-volume loop shape.

This picture of lung function, as represented by the flow volume loop, is very detailed. A normal loop has an expiratory limb and an inspiratory limb. The expiratory limb has a sharp peak flow indicating the strength of the expiratory muscles, the diaphragm and internal intercostals, with an approximate straight line connecting peak flow and zero flow. The inspiratory limb is bell shaped reflecting the weaker inspiratory muscles and a smooth inspiratory flow pattern. Poor patient effort is always definitely indicated by any rounding of the peak flow as there is no physiologic condition which can result in such rounding. If a patient gives maximum effort during a flow volume loop, successive loops will look almost exactly the same, within one or two percent, unless successive loops trigger airway obstruction. It becomes very evident that a patient is trying to change his spirometric results by observing the variation in flow-volume loop shape. The distinctive shape of the end expiratory limb verifies that all air down to residual volume has been exhaled. An abrupt drop or cut off in flow indicates incomplete exhalation or glottis closure. The inspiratory limb of the flow volume loop should connect at total lung capacity to the beginning of the expiratory limb. If the inspiratory limb goes beyond or to the left of the beginning of the expiratory limb there was not a maximum inspiratory effort. The forced inspiratory flow between 25 and 75% of vital capacity (FIF 25-75 or FIF), should never be more than the maximum forced inspiratory flow (FIFmax).

FVC, peak expiratory flow (PEF), and FIFmax can be read directly from a flow volume loop graph while the forced expiratory volume at one second (FEV1) and forced expiratory flow between 25 and 75% of vital capacity (FEF25-75)), and FIF, all need to be calculated or read from a time volume curve. Observation of a time volume curve's shape or appearance yield little intuitive information. When performing spirometry, it is very useful to obtain a flow volume loop as well as SVC, because if the patient is obstructed, the SVC should be significantly larger than the forced vital capacity. If there is significant obstruction and the SVC is comparable to the FVC, than the inspiratory effort on the FVC was not sufficient.



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Maximum voluntary ventilation, MVV, is a component of spirometry in which the patient breathes as fast and as hard as possible, in and out, for fifteen seconds. The total cumulative volume exhaled is then calculated for the fifteen second duration. This test is useful as an alternative measurement for airway obstruction or to verify airway obstruction in a patient who might be giving sub maximal effort in the flow volume loop, perhaps in a medical legal case. The MVV is also useful in monitoring the progression of neuromuscular diseases. Another component of spirometry, maximum inspiratory and expiratory pressure measurements, measured from residual volume (RV) and total lung capacity (TLC) respectively, are very useful in neuromuscular disease evaluation.

As indicated above, few measurements can be observed directly from a flow volume loop, but observation of their shape is extremely useful in pulmonary diagnostics. For example, the superimposing of flow volume loops can demonstrate immediately the degree of airway responsiveness. As indicated above, a normal loop has a straight line between peak flow and zero flow but any concavity along that line indicates varying degree of airway obstruction with the degree of obstruction in proportion to the degree of concavity. Airway obstruction can be caused by emphysema, bronchitis or chronic bronchitis, asthma, or bronchiolitis obliterans. In the case of emphysema, airway obstruction is caused by small airways collapse on exhalation due to the loss of elastic fibers in and connected to small airway walls. In contrast, bronchitis and asthma result in airway obstruction through the occlusion of airway diameter which is also the case in bronchioles obliterans. Restrictive lung disease such as interstitial lung disease presents a loop which is decreased on the volume scale but also has a very high peak flow with typically no concavity, all due to very low compliance or stiffness of the lung.

Fixed extra thoracic airway obstruction presents as a flow volume loop with expiratory and inspiratory limbs that have been cut off presenting a striking plateau effect. The inspiratory and expiratory plateaus can begin, in some cases, as soon as the expiratory flow reaches 2 liters per second. This condition is caused by a fixed obstruction in the trachea or large airways, such as in tracheal stenosis. It is confusingly referred to extra thoracic because it is in the large airways and not in the lung parenchyma. Variable extra thoracic airway obstruction presents as a loop which only has a plateau of flow rates on the inspiratory limb and a normal expiratory flow limb. This condition can be caused when a tumor within the trachea or main stem bronchi, which is pushed out of the way by the strong forces of exhalation, pops back into an obstructive position by the weaker forced of inspiration, driven by the weaker inspiratory muscles.

An interesting effect I have observed in lung transplant patients is a bi-phasic flow volume loop expiratory limb. During a forced vital capacity maneuver, a normal loop appears, until toward the end of the loop, when an obstructive phase seems to tack on to end of the expiratory phase. It is as if there are two flow volume loops represented in the single maneuver. What is happening is that these patients are often single lung transplant recipients and they have one normal lung, the transplanted lung, and the recipient's remaining diseased lung. Upon exhalation, the normal phase represents the flow from the good lung and then, after its quick emptying, the obstructed flow from the diseased lung becomes evident. It presents a very interesting flow volume loop and each phase is very clear and distinct.

Flow volume loops also can be visually scanned to help in the diagnosis of obstructed sleep apnea. *continued on page 75*

This is evident by a saw toothed pattern in the expiratory phase with the saw tooth pattern decreasing toward end of exhalation. This pattern is caused by the high frequency flapping of the laryngeal pharyngeal tissue upon forced exhalation. Patients with obstructive sleep apnea have the extra soft tissue in this area which characteristically flaps or vibrates and which helps cause the obstruction of air flow during the complete muscle relaxation during sleep, associated with rapid eye movement (REM).

A variant of spirometry which was commonly used thirty years ago to help diagnose beginning small airways disease is the helium iso-flow test which involves performing flow volume loop after the patient has taken three deep breaths of heliox which is 80% helium and 20% nitrogen. A flow volume loop is then also performed by the patient while breathing room air. Helium is a lighter gas and as it is forced through the small airways, results in more laminar flow and therefore, in airways which are obstructed, can significantly improve flow rates. In airways which have no or less obstruction, the lighter helium gas has less affect on flow. The point on the expiratory limb of the flow volume loop at which both room air and heliox begin to match in flow rate is significant as the maximum or earliest flow rate that is controlled by density-dependent flow through the small airways. The lung volume in which the flow of heliox and air is the same is referred to as the helium iso-flow or Visov or closing volume. As small airways disease develops, the air and heliox flow rates and curves will match earlier in the flow volume loop expiratory limb and at a larger lung volume or closing volume. The resulting larger Visov can be used as a sensitive test for evaluating the early development of small airways disease, although this test is less commonly used now.

A procedure called "tubeless spirometry" is not commonly used but is interesting in concept. A volume displacement spirometer, source of 100% oxygen, a CO2 scrubber, and a gurney are needed. For each of three separate trials, the patient lies supine and then on his or her left side and then on the right side. The spirometer is filled with 100% oxygen and a carbon dioxide scrubber, with perhaps barium hydroxide, is attached in line completing a closed re-breathing system and the patient breaths normally for four minutes in each of the above described positions. Oxygen consumption is actually being measured and the rate of oxygen consumption remains the same for each position but the functional residual capacity (FRC) is shifted for each position in a characteristic fashion. The baseline or FRC point shifts up or down in relation to the comparative functional volume and the measured FRC is different and is calculated. When the patient is lying on the left side the right side is dominant with more ventilation and less blood flow due to gravity. When laying on the right side the left side is dominant with less blood flow but the heart, of course, results in less ventilation. The characteristic patterns in FRC indicate relative lung function between the right and left lung during this spirometric procedure without the use of a tracheal tube, thus the term, "tubeless spirometry".

Finally, I would like to add a comment about FEF25-75. The American Thoracic Society (ATS) standards and guidelines indicate that the FEV1 is the only reliable parameter for observing changes is airway flow rate and that FEF25-75 is an unreliable measurement because of device and technologist variation. In our laboratory, the FEF25-75 is considered very reliable and that is largely due to the consistent effort on the part of our technologists to give clear directions during repeat measurements while always encouraging maximum effort.

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