



SPIROMETRIC STANDARDS

by Jim Harvey MS, RPFT, RCP

The following is a second look at spirometry, which is the most important test in the pulmonary function arsenal. In part one, published previously in *Focus Journal*, we covered the meaning of spirometry, the structure of the test, diagnostic indications, and variant procedures. In Part II we will cover equipment, testing techniques, and standards of calibration and quality assurance. As we saw in Part I, spirometry appears to be a simple test but in reality, it might be the most complex.

Spirometry is not only the most important but the most commonly performed pulmonary function test. For the amount of effort on both the technologist's and patient's part, it gives the most information. As we saw in part one, spirometry produces a large amount of information using relatively simple machines. Spirometers can be divided into volume displacement devices and pneumotachograph devices. Volume displacement devices have a set physical structure into which the expired gas is collected and measured. The first type of volume displacement device is the water seal spirometer. The water seal spirometer consists of a metal canister with a solid core. Inside the middle of the core there is a tubular passage through which expired and inspired air travels up and over causing a bell to float up or down in water found within a chamber around the core's edge. As the patient breathes in and out either forcefully or tidally, the bell floats up or down proportionally. The bell deflection can be measured directly through a pin attached to the outer edge of the bell which marks a kymograph with paper attached or a carbon rod potentiometer can be attached to the bell which slides through magnetic chamber causing electrical currents to be produced and recorded in proportion to the amount and speed of the bell's deflection. The advantage in this and other volume displacement spirometers is that they are very sensitive to very small or slow volume deflections and they hold their calibration over a long period as long as the mechanical integrity of the volume displacement device is maintained. The disadvantage to this and other volume displacement devices is that their frequency response is not as high compared to pneumotachographs. For spirometers, frequency is measured in cycles per second and one cycle per second is one Hertz. Also volume displacement devices can be cumbersome and in the case of water seal spirometers, the

water can be spilled and might be a source of contamination. A general disadvantage of volume displacement devices is that they are challenging to keep clean.

Another type of volume displacement device is the dry rolling seal. This device can be thought of as cylinder on its side with a piston sliding back and forth within a drum and a tube attached to the inside. As the patient breathes in and out, the piston is displaced back and forth with either a pen and kymograph or potentiometer attached to record volume displacement and flow. The dry rolling seal spirometer has little resistance and is considered the most effective volume displacement device. Finally there is a class of volume displacement devices which are built on the model of either a vertical or horizontal bellows. Using the same potentiometer or kymograph tracing technique, they are referred to as a wedge or bellows.

Pneumotachograph spirometric devices include the pressure differential pneumotach. This device consists of a chamber, through which the patient blows, and is divided by a screen or series of screens. Tubes leading to pressure transducers lead from each side of the screen and as the patient blows the pressure differential across the screen is measured. The measured pressure differential is proportional to the flow. The pressure differential pneumotach only directly measures pressure and from those measurements flow is calculated and since flow is volume per time, volume itself can be calculated. When calibrating a pressure differential pneumotach one simply attaches a three liter syringe and pushes in three liters using three different flows, fast, medium and slow. If the device successfully measures the three liters at these three different flows than the flow and pressure measurements must be correct. Another type of pneumotachograph is the hot wire pneumotach. A similar chamber as the pressure differential houses a series of wires across the air flow instead of screens. The wires are heated by means of a current as a component of a Wheatstone bridge. As the patient blows through the pneumotach, the resultant cooling of the wires and decrease in electrical resistance, is directly proportional to the flow. Volume can then be calculated. The heated wire has the advantage of resisting the buildup of secretions. A final type of pneumotach is the impellor pneumotach in which an impellor spins and its rate of rotation is measured by the interruption of a light source shining across the impellor path and picked up by photometers on the other side of the chamber. These can be very accurate but are not suitable for exercise studies or maximum voluntary ven-

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tilation studies since those studies involve reverse changes in rotation, something with which impellers have difficulty due to factors of momentum.

In general, pneumotachographs have much faster frequency responses and are either disposable or very easy to clean. Of course with the American Thoracic Society (ATS) recommended use of HEPA filters during all patient testing, pneumatics can be used on successive patients without cleaning. The ATS recommends that all spirometry measuring devices both volume displacement and pneumotachograph, be calibrated at least daily, but volume displacement devices can usually be trusted to keep their calibration through the day.

The ATS now in conjunction with the European Respiratory Society has set standards for all spirometers. Spirometers should be capable of accumulating expired volume for at least fifteen seconds and should be capable of measuring volumes of at least 8 liters (BTPS) with an accuracy of at least $\pm 3\%$ of reading or ± 0.050 liters, whichever is greater, within flows between 0 and 14 liters per second. The American Thoracic Society/European Respiratory Society (ATS/ERS) also has recommendations for minimum flows for spirometric devices and those requirements include the total resistance with any tubing or filters attached in line. For other specific details on ATS/ERS equipment requirements check the ATS website.

The fact is that all commercial available spirometers meet or well exceed ATS standards and when choosing a device one should look at size and space considerations, ease of use, friendliness of software, and the company's service history. One of my main recommendations is that a device should be

chosen which is in the beginning of its market life. In another words, buy a device which will remain as the current model for as long as possible.

Obtaining successful and meaningful spirometric results for a patient is an art and involves significant effort and commitment on the behalf of the technologist. How loud the commands are given is not as important as is the technologist's enthusiasm. I prefer the word "blast" to "blow out". The enthusiastic coaching and body language is crucial to meaningful results.

Start and end of test criteria are specific and are discussed in the ATS guidelines. At least three acceptable maneuvers should be obtained and the technologist should watch for fatigue after more than seven or eight. For patients with severe obstruction or older patients, exhalation times of greater than six seconds are frequently needed although exhalation times of greater than 15 seconds do not usually provide additional information. If one encounters significant variation in patient effort, most commonly found in medical legal cases, an included written note is important, explaining the technologist's thoughts about the patient and the accuracy of the testing. The equipment should have the capacity to signal the technologist that the ATS end of test criteria have been met. I have found that a common challenge is encountered when patients, nearing the end of exhalation, sometimes close their glottis or just stop blowing. I tell them that "even though you think you are empty, keep blowing out until I tell you to breathe in!" There are patients who have a strong and chronic cough making it difficult to obtain a good representation of a flow volume loop. A few of the pulmonary function device manufactures have software which allows the technologist to combine successive partial flow volume loops to produce one which is acceptable, although this is not technically allowed by ATS guidelines. An important point to make is that there is only one interpretation of a rounded peak flow on the expiratory limb of the flow volume loop and that is poor patient effort, as there is no physiologic condition which could cause a rounded peak expiratory limb.

A minimum of three acceptable maneuvers must be completed and acceptability is achieved when the difference between the largest and the next largest forced vital capacity (FVC) is ≤ 0.150 liter and the difference between the largest and next largest forced expiratory volume in the first second (FEV1) is ≤ 0.150 liter. If these criteria have not been met within three maneuvers then additional maneuvers should be attempted, up to eight. The flow volume loop to be reported and graphed should be from the loop with the highest sum of FVC and FEV1. Please refer to "Standardization of Spirometry" as presented at www.thoracic.org/sections/publications/statements/index.html for reporting criteria for forced expiratory flow between 25 and 75% of FVC (FEF25-75), peak expiratory flow (PEF), and other values.

All spirometric values should be presented in BTPS which stands for body temperature and pressure, saturated. When using volume displacement spirometers, the temperature should be measured during each test. When a patient performs a flow volume loop, the air leaving the lung is 35°C and saturated with water vapor. As soon as the air enters the spirometer there is instantaneous cooling to ambient temperature but there is much variation depending on length of tubing and whether there is an inspiratory or expiratory effort. There can be a 10% variation in BTPS calculations based upon these variances. With heated pressure differential pneumotachs, the inspiratory and expiratory phases can result in larger errors with high-

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menu to the right with similar functions, click for written narrations, zoom to further examine, or hover and the "pick point" will light up. A not very obvious feature at the top of each section is a list called "See Also...". The choices include some but not all of these; a back view of the anatomical model, "Did you know?" for interesting facts, cross-sections, and details of involved organs. Each topic has animations, 100's of graphics, and thousands of descriptive links. The left sidebar has links to each system and also has direct links to animations, tutorials, and descriptions. The descriptions button takes you to an index of hundreds of terms and "Did you know?" facts. A couple of examples of the "Did you know" are – "Did you know that your brain continues to send out electrical wave signals approximately 37 hours after death?" or "The eye muscle is the fastest reacting muscle of the whole body. It contracts in less than 1/100th of a second."

There were a few navigation difficulties that I had. One was that the advertisements are so close to the page content that I ended up clicking on some of them by mistake and having to back track to the page again. Also, some of the drop-down menus lay over other clickable parts of the page and I had to open and close the menus a couple of times to get what I wanted. That was a bit awkward. I also really had to explore the site a couple of sessions before I realized the breadth of the information. I did find it fun. The interactive aspect makes it very engaging to use. It would make an excellent reference for educators. And, of course, a great place to get in touch with your "Inner Self". I think it would knock the socks off of Socrates (pronounced So-CRATE-eez, if you are a Bill and Ted fan) and Aristotle.

To contact Innerbody directly: phone 602-889-7542, e-mail Inquiry@innerbody.com, or snail mail 1825 E. Northern Ave., suite 175, Phoenix, AZ 85020.

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er flows and with inhalation of test gases. Air filters also change the dynamics of BTPS calculations and we have found that reported volumes can be off by 7%.

Calibration checks with either volume displacement or pneumotach systems should be done at least once per day. A three liter syringe should be injected at least three times to give a range of flows varying between 0.5 and 12 liters per second. The volume of each injection should meet the accuracy requirement of $\pm 3.5\%$. A linearity check should be performed weekly using a three liter syringe to deliver three relatively constant flows at a low flow, then three at a mid range flow, and then three at a high flow, also with an accuracy of $\pm 3.5\%$. All calibration checks should be recorded. Finally, once per week, a standard subject should be tested for validation of flow volume shape and the general performance of the device.

Spirometry seems like the simplest test we perform and the devices also seem simple with relatively few moving parts. But in reality, it has dawned on me, after having written these articles, that spirometry might be the most complex test we pulmonary physiology technologists have in our arsenal and certainly the most widely used and important.

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