Spirometry and Other Pulmonary Function Tests

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Pulmonary function tests provide important clinical information in patients with pulmonary disease. Spirometry gives accurate, rapid information regarding the presence or absence of obstructive or restrictive lung disease and the response to bronchodilators. Particular attention to technique is necessary for valid results. Further information on pulmonary function is provided by the measurement of static lung volumes by dilution techniques or body plethysmography; in some instances lung compliance measurements are indicated.

Pulmonary function tests have assumed an important role in the clinical assessment of patients with cardiopulmonary disease. An ever increasing number of tests is being described, and the physician is faced with questions regarding the indications for these tests and their interpretation and implications in the individual patient.

Lung function may be divided into two major areas: (1) the bellows function of the lung, which is concerned with the movement of atmospheric gas into the alveoli and the removal of alveolar gas from the alveoli; and (2) the gas exchange function of the lung, which is concerned with the transfer of gas between the alveoli and the blood in the pulmonary capillaries. This paper will concentrate on the bellows function of the lungs, since pulmonary gas exchange is not within the purview of this discussion.

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Under routine circumstances, the bellows function of the lungs is assessed by the measurement of dynamic and static lung volumes, and these measurements are usually referred to under the global term "pulmonary function tests." The movement of gas into and out of the alveoli is affected by the mechanical properties of the respiratory system: specifically, resistance to air flow and the compliance of the system, and the state of the respiratory musculature. Alterations in these musculo-mechanical properties of the respiratory system cause characteristic changes in the static and dynamic lung volumes which allow a physiological diagnosis to be made.

The simplest tests, and, fortunately, also the most valuable, are those obtained from spirometry. The spirometer is a device which measures exhaled or inhaled volume per unit time. The simplest type of spirometer is the water-sealed bell; other types, which are more convenient and portable, include the waterless—bellows or rolling seal—types, and the electronic spirometers (Table 1). The latter may not be as accurate as the water-sealed bell-type spirometer.[1] A discussion of the

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Table 1. Spirometers	
Type	**Remarks**
Water-sealed bell	Accurate, simple, but cumbersome
Waterless: Bellows, Rolling seal	Relatively expensive, versatile
Electronic	Portable, not as accurate as water-sealed bell

minimum requirements for office spirometry is contained in a report of the American College of Chest Physicians.[2]

Although many physiological measurements are available from spirometry, for clinical purposes the most useful measurement is the forced expiratory spirogram (Figure 1).

Technique

An accurate spirogram is dependent on proper technique.[2-4] First, it is essential that the spirometer be properly calibrated using a reference calibration syringe capable of accurately delivering a minimum of three liters. Secondly, the paper speed on the spirometer should be checked for accuracy and the spirogram should not be recorded at a speed slower than 20 mm per second. The subject should be standing or seated comfortably and a nose clip applied. The instructions given to the subject are of great importance and every attempt should be made to assure that the subject comprehends them: he must breathe in as far as he can and then, on signal, should blow out as hard and as fast as he can, continuing until he cannot blow out any further. The subject is exhorted during the actual procedure to produce a maximal effort. One or two trial runs are useful before actual recording. The spirometer paper speed must be at the correct rate (20 mm/sec or more) before exhalation begins. At least three spirometric tracings should be obtained at any one testing session; the spirograms should not differ by more than five percent in the forced vital capacities (FVC) between the two best tracings. The record should continue for at least ten seconds. The record should be labeled with the patient's name, date, and the volume and the time calibrations, and the results expressed at Body Temperature and Pressure Saturated (BTPS).

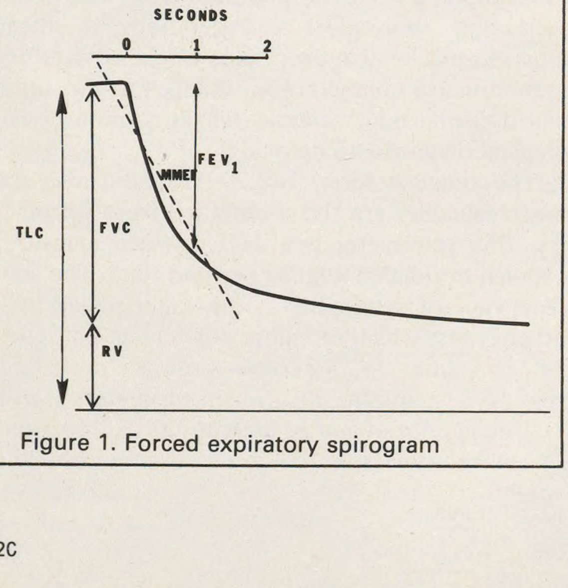

Figure 1. Forced expiratory spirogram

From the tracings, the total volume expired—the forced vital capacity (FVC)—and the volume expired in the first second—the forced expired volume in 1 second (FEV_1)—are measured (Figure 1). Standard measurements also include the maximum mid-expiratory flow rate (MMEF), which is the expiratory rate in the middle portion of the spirogram (Figure 1), ie, between 25 and 75 percent of the total volume expired; this is also known as the forced expiratory flow ($FEF_{25-75\%}$). Tracings where the base line volume is not constant and shows a small decrease (<100 ml) before the forced expiration should be "back extrapolated" to zero time (Figure 2). Tracings showing a greater initial decrease in volume are discarded, as are tracings suggestive of suboptimal effort (Figure 3). The measurements from the best spirogram (greatest forced vital capacity) are reported.

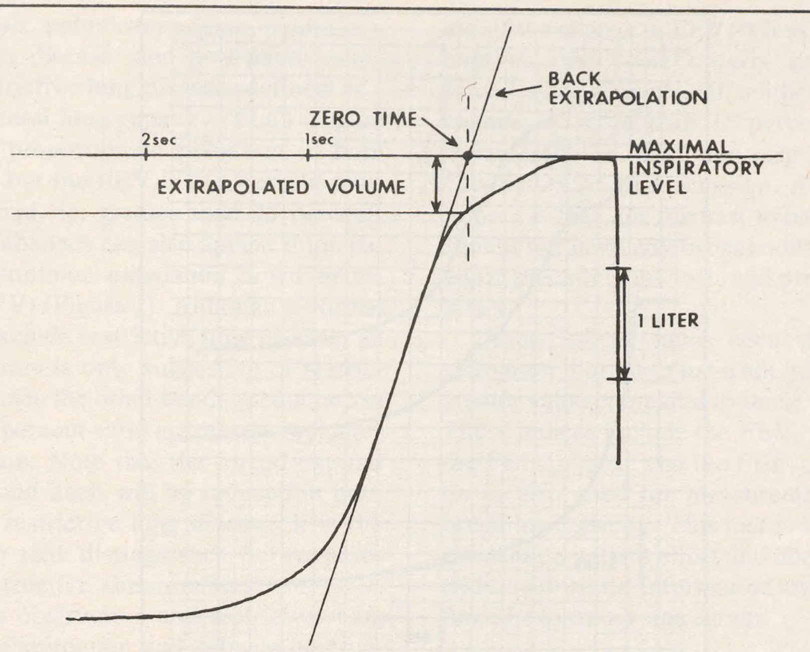

Figure 2. "Back-extrapolation" on spirogram
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Interpretation

The interpretation of the spirogram is based on the deviations from the predicted values for any given subject. Predicted values based on sex, age, and height have been published by several workers[5-7]; by convention, actual values of the forced vital capacity (FVC) and the forced expired volume in 1 second (FEV_1) greater than 80 percent of the predicted values are considered normal. The ratio of FEV_1 to FVC, which provides an index of the expiratory flow rate, is an excellent indicator of the airways resistance. In the laboratory at the University of Kentucky Medical Center, values of FEV_1/FVC, percent less than 75 percent correlate with airway obstruction; in other laboratories, this figure is taken as 70 percent.[4]

The alterations in the forced expiratory spirogram which occur in various disease states are shown in Table 2.

1. If the spirogram shows normal values (>80 percent of predicted) for the FVC and FEV_1 and the ratio of FEV_1/FVC is greater than 75 percent, no clinically significant obstructive or restrictive lung disease is present. In this circumstance, if the maximum mid-expiratory flow rate is markedly reduced, some workers[8] have interpreted this to suggest that small (<2 mm diameter) airway dysfunction is present. However, this view is challenged by other workers.[9,10] Suffice it to say that, for clinical purposes, a spirogram with normal values for the forced vital capacity, the forced expired volume in 1 second, and the FEV_1/FVC ratio may be considered to indicate the absence of restrictive or obstructive lung disease.

2. Obstructive lung diseases (which include asthma, chronic bronchitis, and emphysema) are indicated by a reduction in the FEV_1/FVC, percent ratio. Although both the FVC and FEV_1 are reduced with increased airway obstruction, the reduction in FEV_1 is disproportionately greater than the reduction in FVC. In the early stages of airway obstruction, the actual values of the forced vital capacity and the forced expired volume in 1 second may be greater than 80 percent of the predicted values; this is due to the fact that the pre-

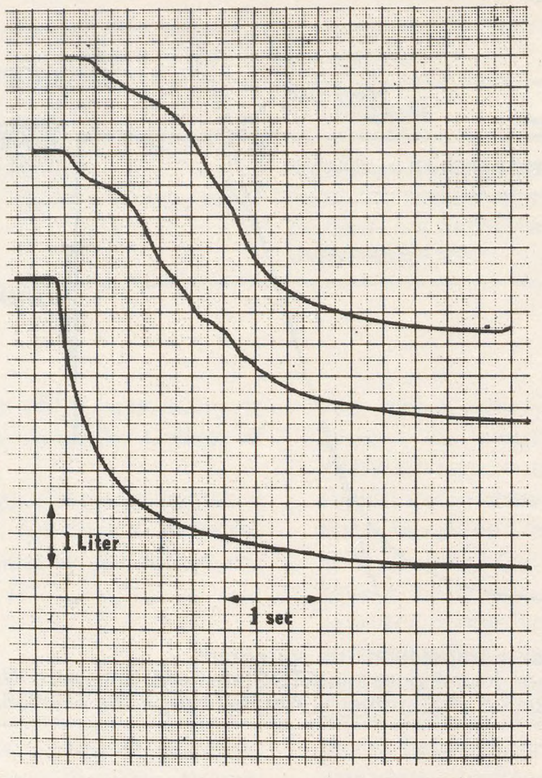

Figure 3. Representative spirograms. The lowest curve indicates good performance; the upper two curves show poor performance, with convexities to the right and non-systematic variable flow rates

Table 2. Dynamic Lung Volumes

	Obstructive	Restrictive
FVC	↓	↓
FEV_1	↓	↓
FEV_1/FVC	<75%	>75%

FVC=Forced vital capacity
FEV_1=Forced expired volume in 1 second

dicted values are taken from population studies and do not, of course, represent the actual predicted values for the individual patient. However, the FEV_1/FVC, percent ratio will still be reduced. As the disease progresses, both the forced vital capacity and the forced expired volume in 1 second will fall below 80 percent of the predicted values. The spirogram will not distinguish between airway obstruction due to predominant emphysema, chronic bronchitis, or asthma.

3. Restrictive lung disease may be associated with such problems as sarcoidosis, interstitial

pulmonary fibrosis, pulmonary edema, pulmonary collagen vascular disease, and post-pneumonectomy state. Restrictive lung disease, defined as a decrease in the total lung capacity (TLC) (Figure 1) will cause a proportionate reduction in both FVC and FEV_1, but the FEV_1/FVC, percent ratio will remain normal, ie, greater than 75 percent. However, these changes can also appear if the patient does not continue exhalation down to residual volume (RV) (Figure 1). Although a normal spirogram can exclude restrictive lung disease, an abnormal spirogram is only suggestive of restrictive lung disease. On the other hand, a reduction in the FEV_1/FVC, percent ratio accurately indicates airway obstruction. Note that the forced expired volume in 1 second itself will be reduced in both obstructive and restrictive lung disease; it is the FEV_1/FVC ratio that distinguishes between restrictive and obstructive abnormalities.

4. When both obstructive and restrictive lung disease exist, the spirogram will indicate obstruction according to the criteria in (2) above, but static lung volumes, specifically the total lung capacity, will need to be measured to assess the presence of restrictive lung disease.

5. It cannot be stressed too strongly that the maximum mid-expiratory flow rate will be reduced whenever the FEV_1/FVC ratio is reduced and may also be reduced when a restrictive defect is present on the spirogram.[9] Therefore, in the presence of an abnormal forced vital capacity or forced expired volume in 1 second or FEV_1/FVC ratio, the maximum mid-expiratory flow rate can provide no information on small airway function.

6. If the spirogram indicates airway obstruction, the degree of reversibility of the obstruction needs to be assessed.[11] The most convenient method is to take the baseline spirometric measurements as outlined above and then repeat the study after administration of a bronchodilator drug (isoproterenol, metaproterenol, or isoetharine) by inhalation. In the laboratory at the University of Kentucky Medical Center, two puffs (1.3 mg) of metaproterenol are used and the study is repeated after 20 minutes. The control and post-bronchodilator values are compared; if there is a greater than 15 percent change in the baseline FEV_1 value (eg, from control FEV_1 of 1.2 liter to 1.4 liter post-bronchodilator, a change of 17 percent), the obstruction is considered partially reversible and bronchodilator therapy is appropriate. If the change in FEV_1 is less than 15 percent of baseline, the same criteria are applied to the forced vital capacity. If neither FEV_1 nor FVC change by more than 15 percent, the patient is considered to be non-responsive to bronchodilators on that occasion. An important point to note is that, for this test to be valid, the patient should not have any bronchodilator drugs in the 6 hours preceding the test, and preferably not for 12 hours.

Other indices have been derived from the spirogram, but these have not been of significantly greater value compared to those mentioned above. These indices include the $FEV_{0.5\ sec}$, the $FEV_{3\ sec}$, the $FEF_{200\text{-}1200\ ml}$, and the $FEF_{75\text{-}85\%}$. The spirometer is also used for measurements of maximum breathing capacity. This test is very markedly dependent on patient effort and does not provide any additional useful information over and above the forced expiratory spirogram.

Other Tests

When an abnormal spirogram is obtained, as indicated above, static lung volume measurements may be necessary to exclude the presence of restrictive lung disease. These measurements require more complex equipment and greater expertise than that required for spirometry. The two main methods of measurement are the dilution methods (helium dilution, nitrogen washout) and the body plethysmographic technique. With these methods, measurements of total lung capacity and residual volume and the functional residual capacity (FRC) can be made (Figure 1; Table 3). The total lung capacity value will indicate whether a restrictive lung defect is present; alternatively, a markedly increased (>120 percent of predicted) total lung capacity would suggest the presence of emphysema. In general, static lung volume measurements provide earlier indications of airway obstruction (eg, elevations in residual volume) and accurately indicate the presence of restrictive lung disease (decreased total lung capacity), compared to spirometry.

Flow-volume loops are also being more extensively used for pulmonary function testing.[12] These require a spirometer and an X-Y plotter; the patient is asked to make a forced expiratory ma-

Table 3. Static Lung Volumes

	Chronic Bronchitis	Asthma	Emphysema	Restrictive
TLC	N	N or ↑	↑	↓
FRC	↑	↑	↑	N or ↓
RV	↑	↑	↑	N or ↓

N=Normal
TLC=Total lung capacity
FRC=Functional residual capacity
RV=Residual volume

neuver, as with spirometry, but in this case a recording of volume against instantaneous flow is made. For clinical purposes, the flow volume loop provides virtually the same information as a spirogram. However, the flow volume loop is of particular value in the diagnosis of upper airway obstruction.[12]

Measurements of lung compliance[13] and of respiratory muscle activity are tests that may occasionally be necessary to assess more complex problems, where static and dynamic lung volume measurement results require further delineation, eg, in the patient with a reduced total lung capacity in whom there is doubt as to the degree of abnormality of the lung parenchyma vs weakness/paralysis of the chest wall muscles.

Conclusions

Spirometry provides valuable clinical information. It is indicated as an initial test of pulmonary function in patients in whom restrictive or obstructive lung disease is suspected. Spirometry also provides information on the degree of reversibility of obstructive pulmonary disease, for guidance in therapy. Over a period of time, spirometry is very helpful in the assessment of the degree of improvement or progression of lung disease. Additional pulmonary function tests, such as measurements of static lung volumes, flow-volume curves, lung compliance, and chest wall muscle function, may be indicated, depending on the results of spirometry and clinical considerations.

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