Evaluation of Respiratory Dysfunction (Lung Volumes; Expiratory Flow Rates; Distribution of Ventilation; Gas Transfer)

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ABSTRACT

Commonly used pulmonary function studies which include the forced expiratory spirogram, lung volumes, distribution of inspired gas, and gas transfer (diffusing capacity) are used principally in diagnostic evaluation of patients with pulmonary disease. They are also helpful in the screening of presurgical patients to identify those with high risk of respiratory complications; screening of large populations for patients with early potentially reversible obstructive lung disease; in following the course and response to treatment of patients with known pulmonary disease; and to allow prediction of prognosis in patients with chronic obstructive lung disease. The test results are sufficiently nonspecific so that major errors in interpretation will be made unless ample clinical information pertaining to the patient's history, physical findings and chest roentgenogram is available at the time the test is interpreted. Otherwise, rather general statements concerning the significance of test results must be used to avoid misleading statements regarding the presence or absence of specific respiratory disease.

Introduction

Commonly used tests of pulmonary function include measurement of lung volumes, analysis of flow rates during a maximal forced expiration (the forced expiratory spirogram), estimation of the degree of inequality of distribution of ventilation within the lungs and gas transfer or diffusion of gases from alveoli into pulmonary capillary blood. The information obtained from these tests is useful in diagnostic evaluation of patients with pulmonary disease, in preoperative screening of patients to identify those with increased risk of respiratory complications and for screening of a large population to identify individuals with early, asymptomatic pulmonary disease. Serial studies provide a means for evaluating the course and response to therapy in patients with known pulmonary disease. With certain diseases, such as chronic obstructive lung disease, these data provide considerable information concerning prognosis as well.

It should be understood, however, that there are at least two well recognized limitations in interpretations of these test data. First, whereas patterns of abnormality
representing "obstructive airway disease," or "restrictive lung disease" are easily defined, it is rarely possible to make a specific clinical diagnosis. Second, even when a specific abnormality in function is noted, it is impossible to determine what regions of the lung are malfunctioning on the basis of these data. Other techniques, particularly those using radiosotopes, are required for evaluation of regional lung function.

The Forced Expiratory Spirogram

**METHOD OF CALCULATION**

The forced expiratory spirogram (FES) provides a measure of the forced vital capacity (FVC), the forced expiratory volume in one second (FEV₁) the maximum midexpiratory flow rate (MMF, or FEF₂⁵ to ⁷⁵ percent) and the peak expiratory flow rate or maximum expiratory flow rate (PEFR, MEFR). The measured flow rates which include the FEV₁, MMF, and PEFR all relate to the presence or absence of obstructive airway disease. The FEV₁ provides the most useful information concerning prognosis in chronic obstructive lung disease. The MMF is the most accurate estimate of airway resistance and is useful for detecting early obstructive lung disease. The PEFR is not as good an index of airway obstruction but reflects factors important in producing an effective cough. The FVC (a volume measurement) is principally related to the presence or absence of a disease or condition which restricts full expansion of the lungs, (a restrictive abnormality) although serious obstructive airway disease may also affect the FVC. The FES is the most widely used pulmonary function test, is quickly and easily performed on relatively inexpensive equipment and provides more useful diagnostic information in relation to its cost than other test.

**INTERPRETATION OF DATA**

**Diagnostic Evaluation.** With the information provided from the FES, it can be determined, in most cases, whether or not the principal problem relates to obstructive airway disease (obstructive abnormality) or restrictive lung disease (restrictive abnormality). Reasonable quantitation of the defect is usually also possible. In patients with an obstructive abnormality, the typical findings are reduction in most if not all expiratory flow rates (FEV₁, MMF and PEFR). The FVC may remain normal; however, in patients with moderate or severe obstructive abnormality, the FVC may be decreased. A restrictive abnormality (which implies limitation of expansion of the lungs to less than their normal volume) is characterized by a reduction in the FVC while expiratory flow rates (FEV₁, MMF and PEFR) remain normal. In table I are outlined the estimation of degree of abnormality from results of the FES.

In circumstances where the FVC is markedly reduced, the calculated ratio FEV₁/FVC must be used to differentiate
between the effects of a severe restrictive problem versus those of a severe obstructive abnormality. If the calculated ratio is greater than 75 percent, a restrictive problem is most likely present; if it is less than 75 percent, it is an obstructive problem. This ratio varies with the patient’s age and sex, however, being significantly higher in younger females and significantly lower in older persons, particularly males. It is rarely possible from data supplied by an FES to determine whether or not both a restrictive and an obstructive abnormality are present simultaneously. In such circumstances, knowledge of other lung volumes including specifically residual volume (RV) and total lung capacity (TLC) are essential for an accurate interpretation.

Flow-Volume Curves. A graphic display of flow and volume data representing a forced expiration allows recognition of typical patterns representing normal, restrictive and obstructive abnormalities as indicated in figure 1. The interpretation of flow volume curves is discussed in detail by other authors.4,9

Presurgical Screening. Patients undergoing surgery involving general anesthesia, especially those having upper abdominal surgery or thoracic surgery, are subject to high incidence of respiratory complications if significant obstructive lung disease is present. The PEFR is the most useful single test to assess the likelihood of respiratory complications related to obstructive lung disease during and after surgery.8 If the PEFR is greater than 50 percent of predicted or above three liters per second, few respiratory complications are likely to develop; with lower PEFR’s, there is a marked increase in incidence of such complications unless special pre and post-operative respiratory care is given.7 This screening test probably separates patients with the ability to clear secretions by coughing from those who cannot.

Prognosis in Established Chronic Lung Disease. Almost all lung function tests provide some information relative to prognosis in patients with established chronic obstructive lung disease but one of the best single predictors is the FEV₁.1 For clinical
Figure 2. Open circuit nitrogen washout curves. The short vertical lines on the graphs represent the predicted normal curve and are calculated from tidal volume (Vt), anatomic dead space (Vd) and functional residual capacity (FRC). The short horizontal lines are observed values for alveolar nitrogen concentration (N₂). (Top, normal; bottom, obstructive lung disease.)

purposes, probability of five year survival can be estimated as follows: when the FEV₁ is greater than 1.2 liters, there is an 80 percent five year survival; when the FEV₁ is between 0.75 and 1.2 liters, there is a 60 percent five year survival; with FEV₁ below 0.75 liter, there is only a 40 percent five year survival. Presence of other abnormalities such as chronic hypercapnia or very low diffusing capacity reduces these survival percentage figures by 25 percent.

Screening for Early Obstructive Lung Disease. The MMF or FEF₂₅ to ₇₅ percent is the flow rate most highly correlated with directly measured airway resistance. This test is relatively independent of the patient's effort and is often abnormal in patients with early asymptomatic obstructive lung disease when other measured flow rates are still within the normal range. It may reflect a disease of the small airways (less than 1 mm diameter) where the earliest changes are presumed to take place, but it remains normal in a significant proportion of patients with early small airway disease. Other specific tests of lung function, including frequency dependence of compliance and determination of "closing volumes," have been found to identify an even higher proportion of patients with early (small airway) obstructive lung disease but have not come into widespread use in the clinical laboratory because of technical difficulties and expense in performing such tests. It is likely, however, that determination of "closing volumes" will become a suitable screening test in the near future to allow identification of patients with early, presumably reversible, obstructive airway disease. It is beyond the scope of this review to discuss details of these last two tests, but comprehensive reviews are discussed elsewhere.₈,₅,₆,₁₀

Lung Volumes

Method of Calculation

The lung volumes which are of most interest are the vital capacity (VC) (volume of a maximal expiration starting from maximal inspiration), the residual volume (RV) (volume of air remaining in the lungs at the end of a maximal expiration), the total lung capacity (TLC) (sum of vital capacity and residual volume), the functional residual capacity (FRC) (volume of air remaining in the lungs at the end of a normal expiration) and expiratory reserve volume (ERV) (volume of a maximal expiration beginning at the end of a normal expiration). The FRC and ERV are usually measured and used to
calculate residual volume as follows:

\[ FRC - ERV = RV. \]

**Interpretation of Data**

In patients with significant obstructive airway disease, the VC may be normal or decreased. If the VC is decreased, the RV is increased at least in proportion to the reduction in VC. The TLC usually remains normal or may be increased, particularly in patients with pulmonary emphysema, reflecting the high compliance and therefore easy distensibility of emphysematous lungs. In patients with restrictive abnormalities, the VC is uniformly decreased and the RV normal or decreased, resulting in a low total lung capacity. In patients with combined obstructive and restrictive patterns of abnormality, the FES will reveal reduced flow rates and the VC and TLC will also be reduced. In patients with severe obstructive lung disease, some of the methods used for measuring FRC and RV, such as nitrogen washout or helium dilution, may grossly underestimate these volumes, so that care must be taken in their interpretation. In summary, determination of lung volumes reinforces and supplements information concerning obstructive and restrictive abnormalities obtained from performance of the FES.

**Distribution of Inspired Gas**

**Method of Calculation**

The uniformity of distribution of gas in the lungs can be evaluated by multiple breath nitrogen washout during oxygen breathing as shown in figure 2 or by the analysis of a single expired breath for nitrogen following inhalation of 100 percent oxygen. The inequality of distribution of inspired gas in the lungs can be quantitated by such methods but one cannot specify regions of the lung which are well or poorly ventilated.

**Interpretation of Data**

Marked nonuniformity of distribution of inspired gas is characteristic of obstructive lung diseases such as asthma or chronic bronchitis and is most marked in pulmonary emphysema. These tests are also abnormal in the presence of any diffuse parenchymal lung disease, but the degree of nonuniformity is much less severe than that seen in obstructive disease. The presence of an appropriate degree of nonuniformity of distribution of inspired gas supports the diagnosis of obstructive lung disease. Such studies are helpful in separating patients with real obstructive disease from those who are attempting to produce an obstructive abnormality on tests by devious means. If marked abnormality of distribution of inspired gas is noted in the absence of generalized obstructive lung disease, it suggests localized pulmonary disease, such as localized partial bronchial obstruction or large emphysematous bullae. The nonuniformity of distribution of inspired gas in these patients may be the only obvious functional abnormality, and is, therefore, a very important finding. Thus, usefulness of these studies is primarily to support the conclusions from analysis of other test data; however, in a few patients, nonuniform distribution of inspired gas may be the only clue to the presence of localized pulmonary disease.

**Gas Transfer (Diffusing Capacity)**

**Method of Calculation**

The most widely used test of gas transfer in this country is the single breath diffusing capacity test using carbon monoxide. Test results reflect diffusion of gases from ventilated alveoli to pulmonary capillaries filled with blood. Thus, test results reflect the size of the functional alveolar-capillary (A-C) membrane surface area and thickness of the membrane. If one reduces the total surface available for gas transfer
either by reducing the volume of lung ventilated, the volume of capillaries filled with blood or increases the thickness of the A-C membrane, the diffusing capacity measurement will decrease. In addition, non-uniform distribution of ventilation and blood flow in the lung may also have a significant effect on the calculated diffusing capacity even though the A-C membrane is normal and the total surface area is not reduced. Examples of disease states which would result in reduction in diffusing capacity would include (1) lung resection or destruction of lung parenchyma, (2) complete bronchial obstruction to major areas of one or both lungs, (3) pulmonary vascular obstruction, as in pulmonary embolism, (4) increased diffusion distance, as in interstitial pulmonary fibrosis and (5) decrease in concentration of hemoglobin in pulmonary capillaries, as in anemia.

Although reduction in diffusing capacity has been equated with reduction in physiologic diffusion in the lung, many of the changes seen in test results can be explained by patterns of abnormal distribution of ventilation in relation to perfusion within the lung. Whether or not the diffusing capacity test in fact measures the physiologic process of diffusion and whether or not it reflects certain kinds of ventilation-perfusion abnormalities, it remains a useful test procedure.

**INTERPRETATION OF DATA**

In patients with diffuse parenchymal lung disease, such as idiopathic diffuse interstitial fibrosis, reduction in the diffusing capacity may be the first abnormality detectable.

The characteristic changes seen in patients with diffuse interstitial disease of lung are significant restrictive abnormality (low VC and low TLC), normal expiratory flow rates and a single breath carbon monoxide diffusing capacity which is reduced proportionately more than the reduction in TLC. The measurement of diffusing capacity is also useful in following the course of such diseases and evaluating response to therapy. Patients with anemia have a reduction in measured diffusing capacity, which is proportional to the degree of their anemia. Patients with pulmonary embolism may have a normal or a mildly reduced diffusing capacity. The patient with obstructive lung disease who has a marked reduction in diffusing capacity is more likely to have extensive changes of pulmonary emphysema whereas the one with a perfectly normal breath holding diffusing capacity is more likely to have chronic bronchitis or asthma. The test, therefore, helps to discriminate between these varieties of obstructive lung disease.

In the patient without evidence of obstructive lung disease, a reduction in diffusing capacity should ordinarily raise the suspicion of one of the several conditions discussed above. In the presence of obstructive lung disease, little can be said concerning the significance of the diffusing capacity except as it relates to the obstructive disease present.

**GLOSSARY**

- **DLCO** Pulmonary diffusing capacity for carbon monoxide.
- **ERV** Expiratory reserve volume. Volume of a maximal expiration beginning at the end of a normal expiration.
- **FEF<sub>25-75</sub>%** Forced expiratory flow between 25 and 75 percent of FVC. (Same as MMF.)
- **FES** Forced expiratory spirogram. Analysis of flow rates during a maximal forced expiration.
- **FEV<sub>1</sub>** Forced expiratory volume in one second.
- **FRC** Functional residual capacity. Volume of air remaining in the lungs at the end of a normal expiration.
- **FVC** Forced vital capacity.
- **MEFR** Maximum expiratory flow rate (calculated from volume tracing), similar to PEFR.
- **MMF** Maximum midexpiratory flow rate. Forced expiratory flow between 25 and 75 percent of FVC. (Same as FEF<sub>25-75</sub>%.)
EVALUATION OF RESPIRATORY DYSFUNCTION

PEFR Peak expiratory flow rate (measured directly by flow meter).

RV Residual volume. Volume of air remaining in the lungs at the end of a maximal expiration.

TLC Total lung capacity. Sum of vital capacity and residual volume.

VC Vital capacity. Volume of a maximal expiration starting from maximal inspiration.

References


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"Blessed is the man who having nothing to say abstains from giving us wordy evidence of the fact."

George Eliot

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