Pulmonary Function Testing

Learning Objectives:

1. Understand the standards for acceptable and reproducible efforts as part of pulmonary function testing.

2. Know the patterns of spirometry (obstructive defect, restrictive pattern, mixed spirometry) and how these correspond to clinical pulmonary disease.

3. Understand how to use lung volumes to define restrictive ventilatory defect, air-trapping and hyperinflation.

4. Be familiar with the normal flow volume loop, and patterns associated with obstructive and restrictive lung diseases. Understand the changes seen with fixed and variable proximal airway obstruction (intra-thoracic and extra-thoracic)

5. Explain what is measured by the DLCO and DLCO/VA and what factors may cause these to increase or decrease.

6. Define the ATS criteria for significant improvement following bronchodilator therapy.

Required Reading:

Crapo RO. Pulmonary Function Testing. NEJM 1994;331:25-30.

Handout – approach to pulmonary function testing

For Additional Study:

Chupp G (editor). Pulmonary Function Testing. Clinics in Chest Medicine. Dec 2001;22:4.

American Thoracic Society. Guidelines for methacholine and exercise challenge testing – 1999. Am J Respir Crit Care Med 2000;161:309-329.

American Thoracic Society. Standardization of spirometry: 1994 update. Am J Respir Crit Care Med 1995;152:1107-1136.

American Thoracic Society. ATS Statement: guidelines for the six-minute walk test. Am J Respir Crit Care Med 2002;166:111-117.

~~Related MKSAP Questions: 2, 4, 9, 12, 14, 17, 45, 49, 61~~

REVIEW ARTICLES

CURRENT CONCEPTS

PULMONARY-FUNCTION TESTING

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PULMONARY-FUNCTION tests provide objective, quantifiable measures of lung function. They are used to evaluate and monitor diseases that affect heart and lung function, to monitor the effects of environmental, occupational, and drug exposures, to assess risks of surgery, and to assist in evaluations performed before employment or for insurance purposes. The indications for pulmonary-function tests are summarized in Table 1. Spirometric examination, the most widely used such test, is the focus of this paper. Spirometry is the measurement of the movement of air into and out of the lungs during various breathing maneuvers. Such examinations should be readily available and routinely used in medical offices and hospitals where patients with heart and lung diseases are treated. Other common tests of lung function include the measurement of lung volumes, airway resistance, carbon monoxide diffusing capacity, and arterial-blood gases.

DIAGNOSTIC INDICATIONS

Pulmonary-function tests are useful in diagnosing and managing pulmonary diseases. The recommendations of the National Asthma Education Program indicate that such testing is essential in the diagnosis and management of asthma because of evidence that both patients and physicians have inaccurate perceptions of the severity of asthma that contribute to delays in treatment.[1] Indeed, underestimation of the extent of airflow (airway) obstruction is associated with increased mortality in asthma.[2]

Pulmonary-function tests can identify abnormalities of lung function that might otherwise be overlooked and can exclude the possibility of some respiratory disorders such as chronic obstructive pulmonary disease. Physicians cannot identify obstructive or restrictive patterns reliably from history taking and physical examination alone.[3-5] When physicians ordering lung-function tests were asked to predict the results, they correctly predicted an obstructive pattern 83 percent of the time.[4] However, predictions of normal or restrictive patterns were correct only about half the time.[4] Besides identifying abnormalities, lung-function tests allow the severity of an abnormality to be quantified and the presence of reversible airflow obstruction to be determined.

Pulmonary-function testing is sometimes indicated when there may be more than one explanation for a patient's symptoms. For example, a smoker who presents with dyspnea and obvious signs of congestive heart failure may also have obstructive lung disease. Failure to recognize and treat both disorders may limit the therapeutic response.

SCREENING AND MONITORING

Lung-function tests are included in many evaluations of fitness and some routine physical examinations. Such testing may provide interesting information, but in the absence of symptoms, physical findings, or risk factors its clinical usefulness is questionable. There is little evidence to support a policy of screening the general population with spirometry.[6] Some subgroups (e.g., cigarette smokers and people exposed to known agents of lung injury, such as asbestos or diisocyanates) are at higher risk of lung disease; screening and monitoring are appropriate for them.[6,7] It has been suggested that about 15 percent of cigarette smokers have an accelerated decline in the maximal volume of air exhaled, after a maximal inhalation, in the first second of a forced exhalation (i.e., the forced expiratory volume in one second, or FEV_1); ultimately, this condition leads to airflow obstruction and the possibility of early disability and death from chronic obstructive pulmonary disease.[8] Although the rates of loss of FEV_1 in smokers and nonsmokers overlap, nonsmokers tend to lose FEV_1 at a rate of 20 to 30 ml per year, whereas "sensitive" smokers (those with an accelerated decline in FEV_1) lose FEV_1 at a rate of more than 60 ml per year. In people under 35 years of age, cessation of smoking is associated with improved lung function; for those older than 35, the accelerated decline in lung function slows to the normal rate associated with aging.[8-10] Smokers with one normal spirogram cannot rest easy; they may still have an accelerated loss of lung function that is detectable only by serial measurements. Smokers may be more likely to stop smoking if they are informed of such functional abnormalities.

Serial measurement of lung function (monitoring) may be useful in tracking pulmonary expressions of diseases, quantifying responses to therapy, and making early diagnoses of lung injury after occupational exposures and drug or radiation therapy. Many diseases, including heart failure, rheumatoid arthritis, inflammatory bowel disease, and vasculitis, affect the lungs either directly or as a result of the adverse effects of treatment.[11] Monitoring lung function allows the physician to identify and quantify pulmonary involvement in such diseases. For example, serial measurement of vital capacity (VC) may help a physician

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Table 1. Indications for Pulmonary-Function Tests.

Diagnostic
To evaluate symptoms, signs, and abnormal results of laboratory tests
Symptoms: cough, dyspnea, wheezing, orthopnea, or chest pain
Signs: overinflation, expiratory slowing, cyanosis, chest deformity, wheezing, or unexplained crackles
Abnormal results of laboratory tests: hypoxemia, hypercapnia, polycythemia, or abnormal chest radiographs
To measure the effect of disease on pulmonary function
To screen persons at risk for pulmonary disease
Smokers
Persons with occupational exposure to injurious substances
Some persons at the time of a routine physical examination
To assess preoperative risk
To assess prognosis
Monitoring
To assess effectiveness of therapeutic interventions
Bronchodilator therapy
Steroid treatment for asthma, interstitial lung disease, and the like
Management of congestive heart failure
Other
To provide information on the course of diseases affecting lung function
Pulmonary disease, such as obstructive airways disease and interstitial lung disease
Cardiac disease, such as congestive heart failure
Neuromuscular disease, such as Guillain–Barré syndrome
To assess current status of persons with occupational exposure to injurious substances
To detect adverse reactions to drugs with known pulmonary toxicity
Evaluation of disability or impairment
To assess patients as part of a rehabilitation program
Medical
Industrial
Vocational
To assess risks for an insurance evaluation
To assess the condition of persons for legal reasons
Social security or other program involving government compensation
Personal-injury lawsuits
Other
Public health
Epidemiologic surveys

quantify a patient's response to therapeutic agents in congestive heart failure. In the Framingham study, decreases in VC were a better predictor of heart failure than were symptoms, examinations, or radiographic findings.[12] Improvements in VC may also indicate recovery from congestive heart failure.[13]

Numerous drugs are associated with lung injury.[14,15] The role of pulmonary-function testing in monitoring for drug toxicity is not clearly defined. In the case of amiodarone hydrochloride, an antiarrhythmic agent, it is quite controversial, but monitoring of lung function may confirm or provide an early indication that an adverse pulmonary reaction has begun. The development of pulmonary fibrosis can be monitored with lung-function testing in patients undergoing cancer chemotherapy or radiation therapy involving lung parenchyma. Lung-transplant recipients are commonly monitored with lung-function tests to detect early evidence of bronchiolitis obliterans.[16,17]

Monitoring is useful only when adequate base-line studies are available for comparison. A change from a patient's base-line value is more likely to indicate pulmonary injury than is the traditional comparison of values measured in the patient with reference values obtained from population studies. Changes from base line that are as small as 5 to 10 percent may be substantial for a person and could be missed if only reference values are used in the comparison. Consider, for example, a 40-year-old man who is 175 cm tall. His predicted VC, based on reference values, is 4.99 liters (normal range, 3.79 to 6.11). If his VC at base line was 6 liters, it could decrease by up to 37 percent before his test results fell below the normal range.

The frequency and kinds of pulmonary-function tests vary with the situation. If the primary involvement is in the airways (for example, in a lung-transplant recipient at risk of bronchiolitis obliterans), spirometric testing is adequate. If involvement of the lung parenchyma is likely (for example, in a patient receiving bleomycin), lung volumes and the carbon monoxide diffusing capacity (DLCO; also known, especially in Europe, as "transfer factor") should also be measured. In congestive heart failure, lung volumes are primarily affected, and VC is the best index to monitor.

Preoperative Evaluation

Although the role of preoperative pulmonary-function testing remains controversial,[18] its goals are now more clearly defined.[19-21] They include helping to identify patients for whom the risk of surgery is prohibitive and helping to identify patients at increased risk of pulmonary complications, for whom better-informed decisions about preoperative and postoperative care can then be made.

There is general agreement that at the least, the preoperative pulmonary testing of patients for whom lung resection is being considered should include spirometry and measurement of arterial-blood gases. The abnormalities that suggest an increased risk of postoperative pulmonary complications and the need for further evaluation are as follows: VC less than 50 percent of the predicted value, FEV_1 less than 2 liters or less than 50 percent of predicted, or the presence of substantial hypoxemia or hypercapnia. Studies designed to predict postoperative FEV_1 from ventilation or perfusion scans and, in some cases, DLCO and exercise studies may help in further defining the risk.[19-21] Patients whose predicted postoperative FEV_1 is less than 0.8 liter or 40 percent of the predicted value are at very high risk.

For other surgery, the risk of postoperative pulmonary complications generally declines as the distance from the chest to the surgical site increases. Upper abdominal and thoracic operations not involving lung resection are associated with increased risks of pulmonary complications. Smokers and people with signs and symptoms suggestive of lung disease are most likely to benefit from preoperative screening with spirometry and blood gas analysis.[21] Lower abdominal and head-and-neck surgery are associated with lower surgical risks. Spirometric testing and blood gas analysis are likely to help only patients without prior lung-function tests whose preoperative evaluation suggests the presence of pulmonary disease.[21]

Risk and Prognosis in Patients with Known Lung Dysfunction

Low levels of lung function, even in patients who have never smoked cigarettes, are associated with a poor prognosis in patients with heart and lung disease. Studies consistently find that reduced lung function (usually FEV_1) is associated with an increased risk of death from chronic obstructive pulmonary disease, non-neoplastic respiratory diseases, vascular diseases, lung cancer, and all causes of death considered together.[22-25] These findings are consistent among groups of patients, but it is not possible to predict the symptoms or mortality of individual patients accurately on the basis of FEV_1 alone.

Interpretation of Lung-Function Tests

Test quality remains the most important concern in lung-function testing. Variability (noise) is greater in pulmonary-function tests than in most other clinical laboratory tests because of the inconsistency of efforts by patients.[26] The American Thoracic Society (ATS), the European Respiratory Society, and other organizations have published standards designed to minimize the variability in these tests[27-44] (Table 2). The elements that lead to high-quality test results are accurate equipment, good test procedures, an ongoing program of quality control, appropriate reference values, and good algorithms for the interpretation of results. It is tempting to assume that all equipment on the market is accurate. However, a 1990 evaluation of spirometers revealed that only 57 percent met the standards of the ATS for accuracy.[42] Purchasers should insist on evidence that an instrument meets the ATS performance recommendations.[27] A quality-control program for spirometers that uses a calibrated 3.0-liter syringe and a few other simple checks[32] can be conducted easily in a physician's office. Monitoring the accuracy of instruments that measure diffusing capacity, lung volume, and blood gases is more difficult. These machines are best used in settings where there are larger volumes of patients.

The interpretation of lung-function tests usually involves comparing values measured in patients with reference values from studies of populations of healthy nonsmokers. There are substantial differences between the equations used to predict normal lung function, because of differences among the populations studied as well as technical and procedural differences. It is important to select equations for reference use that are well matched with the patients served in a particular office or laboratory. The ATS has published guidelines for making these choices.[33] Physicians unfamiliar with selecting reference values and choosing the lower limits of normal ranges should consult a local pulmonary-testing laboratory with expertise in this area.

The first step in interpreting a lung-function test is to assess and comment on test quality. Spirometric tracings should be examined to make sure they represent adequate effort by the patient, are reproducible, and contain no artifacts that would alter the test results (Table 3). If the requirements for quality are not met, tests should be interpreted (Table 4) with caution. Some technical problems are so important that

Table 2. Sources of Information on the Measurement and Interpretation of Pulmonary-Function Tests.

Type of Information	Reference
Adults	
Practical, how-to manuals or guides	Morris et al.,[38] Enright and Hyatt,[40] Miller,[39] Wanger,[41] Clausen[37]
Standards	
Equipment and procedures	
Spirometry	American Thoracic Society,[27] European Respiratory Society,[28] Morris et al.,[38] Nelson et al.[42]
DLCO	American Thoracic Society,[29] European Respiratory Society[28]
Lung volumes and mechanics	European Respiratory Society[28]
Personnel	Gardner et al.[30]
Computers	Gardner et al.[31]
Quality control	Gardner et al.,[32] Clausen[37]
Reference values and interpretation	American Thoracic Society,[33] European Respiratory Society,[28] Morris et al.,[38] Clausen[37]
Disability or impairment	American Medical Association,[43] American Thoracic Society[44]
Children	
Overall guidelines	Quanjer et al.,[34] Taussig et al.,[35] Zapletal et al.[36]

Table 3. Technical Requirements for Spirometry of Good Quality.*

At least 3 acceptable tests
Full inhalation before start of test
Satisfactory start of exhalation
Evidence of maximal effort
No hesitation
No cough or glottal closure during the first second
Satisfactory duration of test
At least 6 seconds
Up to 15 seconds in patients with airflow obstruction
No evidence of leak
No evidence of obstruction of the mouthpiece
Reproducible results
For FVC and FEV_1, the 2 largest values should be within 5 percent or 0.1 liter (whichever is larger) of each other
If these criteria are not met, continue testing
If the criteria are not met after 8 trials, stop testing and proceed with the interpretation, using the 3 best acceptable tests
Selection of test values for interpretation
Select from tests of acceptable quality
Select the largest values for FVC and FEV_1, regardless of the test used
For indexes of average or instantaneous flow, use values from the test with the largest value for FVC and FEV_1 combined

*Adapted from the statement of the American Thoracic Society,[27] with the permission of the publisher.

they prevent any interpretive statements from being made; other problems reduce but do not totally eliminate the amount of interpretable information. For example, a set of spirograms may contain good information about VC but not about FEV_1.

Figures 1 and 2 show spirograms from a normal subject and two patients with airflow obstruction. With computerized equipment, more than 20 different spirometric variables can be reported. It is important to resist the temptation to use more than a few such variables in the basic interpretation. Increasing the number of variables used in the test increases the number of false positive results.[33] In spirometry, there are several basic variables. VC is the maximal volume of air that can be exhaled after a maximal inhalation or the maximal volume of air that can be inhaled after a maximal exhalation. It can be measured as two variables: forced vital capacity (FVC) and slow vital capacity (SVC). Two other variables are FEV_1 and $FEV_1/VC\%$ (calculated as $FEV_1/VC \times 100$). In most cases these variables suffice to provide all the information needed to interpret a spirogram.

Two basic types of lung dysfunction can be defined by spirometry: obstructive patterns and restrictive patterns. The primary criterion for airflow obstruction is a reduced $FEV_1/VC\%$. Other measurements of flow can be used to support conclusions based on this variable or to assist in making decisions when $FEV_1/VC\%$ is borderline.

A restrictive pattern means that lung volumes are small. The primary criterion for this diagnosis is a reduction in total lung capacity (TLC), the volume of air in the lungs at the end of a maximal inhalation. However, the presence of restriction is commonly inferred from a decreased VC. VC may also be reduced in the presence of airflow obstruction, especially when exhalation time is short. When there is airflow obstruction and VC is reduced, the possibility of restriction can usually be eliminated with evidence of overinflation from the physical examination or chest radiograph. When there is any question about the cause of a reduced VC, TLC should be measured. Even though restriction is defined by a reduced TLC, VC has frequently been demonstrated to be more useful in following the course of restrictive chest diseases.

Table 5 lists the criteria of the ATS for evaluating a response to the administration of a bronchodilator in the laboratory and assessing the importance of

Table 4. Guidelines for the Interpretation of Spirometry.*

Choose statistically acceptable lower limits of normal.
Evaluate and comment on test quality.
Use FVC, FEV_1, and $FEV_1/VC\%$ as the primary guides for interpretation. (Increasing the number of variables in the interpretation increases the incidence of false positive results.)
Values that are well above or well below the lower limits of normal can be interpreted with confidence. Interpret borderline values with caution, using clinical information to make decisions.
The primary indicator of airflow obstruction is a reduced $FEV_1/VC\%$.
Once obstruction is diagnosed, classify the severity using FEV_1 expressed as a percentage of the predicted value.
Determine the response to bronchodilator therapy (see Table 5).
A restrictive pattern may be cautiously diagnosed from the spirometric examination when VC is reduced and $FEV_1/VC\%$ is normal. However, the definitive finding for a restrictive pattern is a reduced TLC.
The severity of restriction should be based on TLC if that value is available, and otherwise from VC.
Restriction cannot be diagnosed from the spirometric examination in the presence of moderate-to-severe airflow obstruction.

*Adapted from the statement of the American Thoracic Society,[33] with the permission of the publisher.

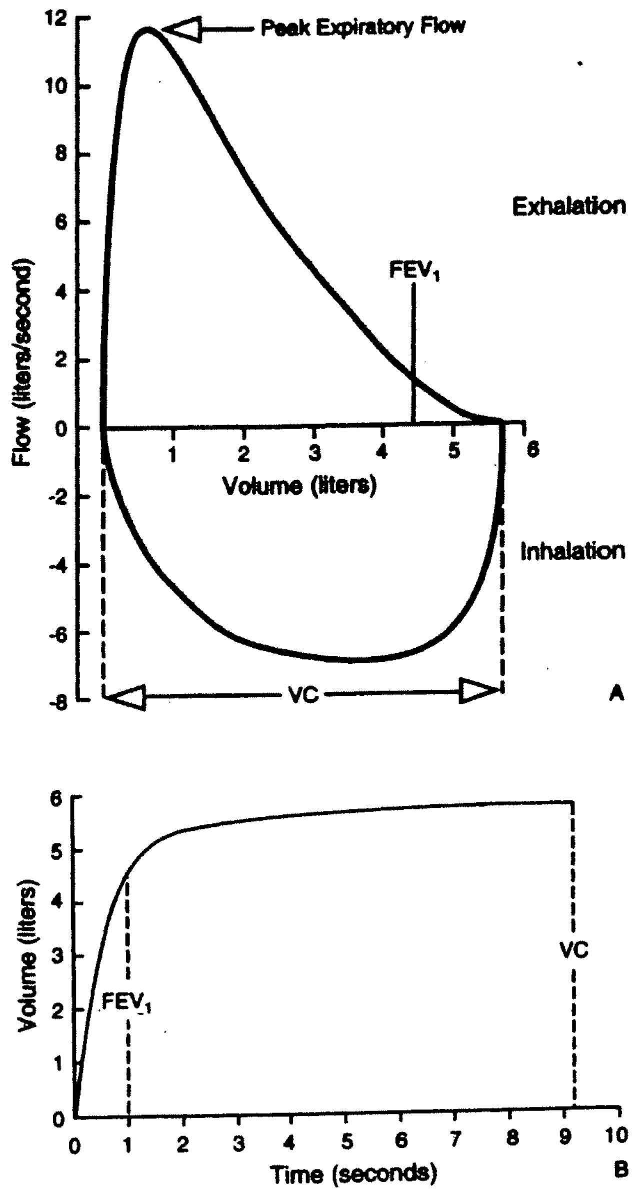

Figure 1. Spirometric Flow–Volume (Panel A) and Volume–Time (Panel B) Curves for a Healthy 52-Year-Old Man 188 cm Tall. In the flow–volume curve the well-defined peak in expiratory flow shows good initial effort. The slightly concave appearance of the expiratory portion of the curve appears with aging alone. In a 20-year-old person, the same pattern could indicate the presence of airflow obstruction. In the volume–time curve good initial effort is shown by the sharp increase in volume from time zero. The long, slow increase in volume shows the age-related decrease in flow at end-expiration. Total expiratory time can be seen only in the volume–time curve.

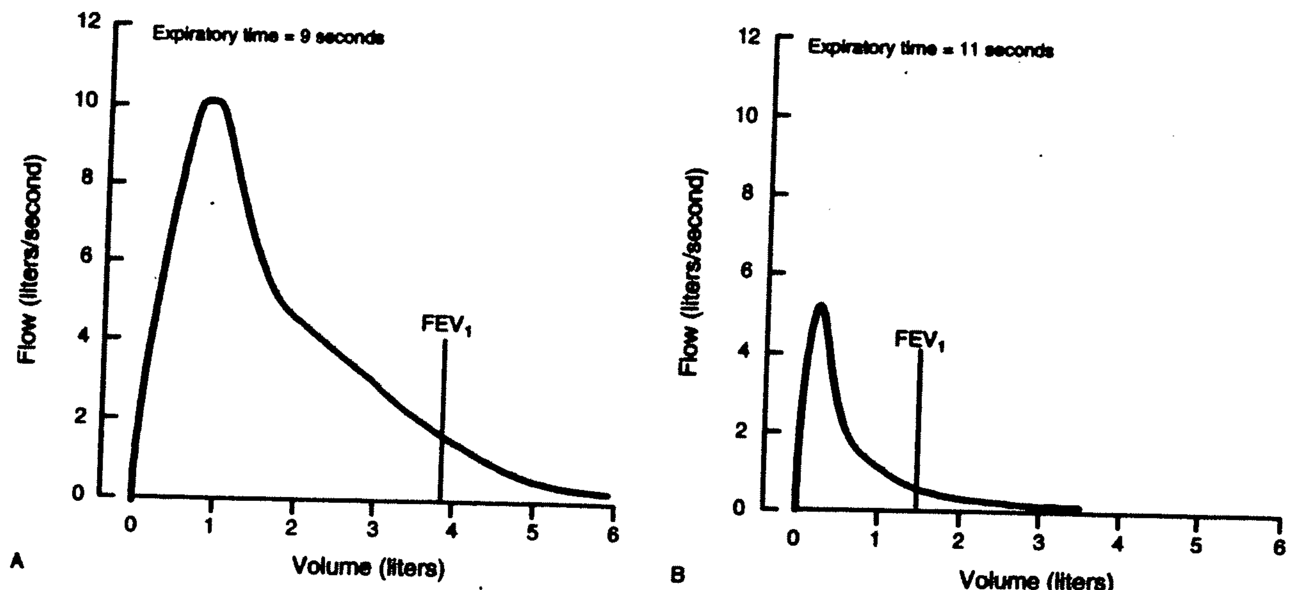

Figure 2. Expiratory Flow–Volume Curves for Patients with Mild and Severe Airflow Obstruction.

Panel A shows the curve for a 45-year-old man 184 cm tall with mild airflow obstruction. The initial effort is good, with early, well-defined peak expiratory flow. The concave character of the descending curve indicates the presence of airflow obstruction. $FEV_1/VC\%$ is reduced at 64 (predicted value, 80), but FEV_1 is normal (92 percent of predicted), indicating that the obstruction is mild. The expiratory flow approaches but does not reach zero, a subtle but important element to look for on the tracing; it may be the only evidence of a problem with the test, because total expiratory time is not seen on the flow–volume curve.

Panel B shows the curve for a 47-year-old man 183 cm tall with severe airflow obstruction. Although peak expiratory flow is reduced, the peak is well defined, indicating a good initial effort. There is a sudden drop in flow after the peak, and the tail of the expiration curve is long. The subject's $FEV_1/VC\%$ is 40. The marked reduction in FEV_1 (34 percent of predicted) indicates the presence of severe airflow obstruction.

changes in FVC and FEV_1 over time.[33] Treating a patient with a bronchodilator medication is a clinical, not a laboratory, decision. A response to this therapy in the laboratory makes a clinical response to therapy more likely; nevertheless, the lack of such a response does not preclude a clinical response to long-term bronchodilator therapy. If the clinical evaluation suggests that such therapy may be effective, it can be instituted and followed by a reevaluation, both clinical and spirometric, in four to six weeks. As when patients are monitored in other ways, patterns of change are more apparent with serial measurements.

Table 5. Response to Bronchodilator Therapy and Changes over Time.*

Measure of Response	Percent Change in FVC or FEV_1 Required for a Substantial Response†	Comment
Current ATS recommendation	12	Both a 12 percent improvement and an absolute improvement of 200 ml are required.
Change from week to week		
Normal subjects	≥12	
Patients with chronic obstructive pulmonary disease	≥20	

*Adapted from the statement of the American Thoracic Society,[33] with the permission of the publisher.

†Changes in FVC must not be due to a longer total exhalation time in persons with airflow obstruction.

Classifying the severity of disease involves several complex issues. A general discussion and specific guidelines are provided in the statement by the ATS.[33]

Conclusions

There are good reasons to seek quantifiable data about lung function. Interpreting the results of pulmonary-function testing requires careful attention to the equipment used, the patient's performance, and the reference values chosen. In cases in which disease or lung injury may develop over time, a person's own base-line values provide the best reference data.

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PULMONARY FUNCTION TESTING

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Systematic Approach to Pulmonary Function Test Interpretation -

1) Is the test interpretable?
2) Are the results normal?
3) What is the pattern and severity of the abnormality?
4) What does this mean for my patient?

SPIROMETRY

Is the test interpretable?

1) Smooth continuous curve
2) Good start of test (rapid upstroke, slightly rounded peak flow)
3) Good end of test (plateau of 1 second or exhalation > 6 seconds)
4) ≥2 acceptable maneuvers with FVC and FEV_1 within 200 cc of each other

Are the results normal? What is the pattern and severity of the abnormality?

FVC > 80% predicted? (Within 95% Confidence Interval)

- ↓ **Yes** ↓ **FEV_1/FVC > 90% predicted? (Within 95% confidence interval?)**
  - ↓ **Yes** ↓ **Normal Spirometry**
  - ↓ **No** ↓ **Obstructive Defect**[1]
- ↓ **No** ↓ **FEV_1/FVC > 90% predicted? (Within 95% confidence interval?)**
  - ↓ **Yes** ↓ **Restrictive Pattern**
  - ↓ **No** ↓ **Mixed Pattern**[2]

Confirm impressions using flow volume loop

[1] A low FEV_1/FVC ratio with an FVC and FEV_1 that are both above predicted can sometimes be seen in healthy adults, including athletes.
[2] Severity of a mixed abnormality is defined by the degree of obstruction.

Severity Classification for PFTs and DLCO as Percent Predicted

	Normal	V. Mild	Mild	Moderate	Severe	V. Severe
FVC	> LL of CI	> 80% & < LL of CI	65-79%	51-64%	35-50%	< 35%
FEV_1	> 100%	80-100%	65-79%	51-64%	35-50%	< 35%
DLCO	> LL of CI	> 80% & < LL of CI	60-79%	40-59%	20-39%	< 20%

Use FVC grade severity of restrictive patterns, FEV_1 for obstructive defects

What does this mean for my patient?

Definition of an Obstructive Ventilatory Defect
A disproportionate reduction in the maximal airflow from the lung with respect to the maximal volume (FVC) that can be displaced from the lung.

Common Causes of an Obstructive Ventilatory Defect

Diseases that cause airway narrowing –

COPD
Bronchiectasis
Asthma
Tracheomalacia

Definition of a Restrictive Ventilatory Defect
A reduction in total lung capacity (TLC). Therefore, **you need lung volumes to definitively diagnose a restrictive defect!!!!**

Common Causes of a Restrictive Ventilatory Defect

Interstitial Lung Disease	Idiopathic pulmonary fibrosis Pneumoconiosis Interstitial edema (heart failure) Sarcoidosis
Space Occupying Lesions	Tumors Cysts
Peural Diseases	Pneumothorax Pleural effusion

Chest Wall Diseases	Kyphoscoliosis Neuromuscular disease (ALS, phrenic nerve paralysis)
Extrathroracic Conditions	Obesity Ascites Pregnancy

<u>Low DLCO</u>

DLCO is decreased in conditions that disrupt the alveolar-capillary surface for gas transfer.

Loss of Surface Area	Lung resection Emphysema Pneumonia
Reduced Blood Flow	Anemia Pulmonary embolism Pulmonary hypertension
Increased Diffusion Distance	Pulmonary alveolar proteinosis PCP pneumonia

<u>High DLCO</u>

Recruitment of Pulmonary Vascular Bed	Exercise Mild CHF Left to right shunt Asthma
Increased Amount of Hgb Binding CO	Pulmonary hemorrhage

TABLE 26

AGE	PREDICTED PaO2	PREDICTED SaO2	PREDICTED CaO2 M	PREDICTED CaO2 F	PREDICTED P(A-a)O2	PREDICTED PaCO2	LOWER LIMIT PaO2	LOWER LIMIT SaO2	LOWER LIMIT CaO2 M	LOWER LIMIT CaO2 F	LOWER LIMIT PaCO2	UPPER LIMIT PaCO2	UPPER LIMIT P(A-a)O2
			ALTITUDE		4000 ft	1219 M	BP 656 mmHg	(MTHb + COHb) = 1					
20	83	95	21.0	18.7	5	33	72	93	18.9	16.5	26	40	18
30	81	95	20.9	18.6	7	34	69	93	18.8	16.4	27	40	20
40	78	94	20.8	18.4	9	34	66	92	18.6	16.3	27	41	22
50	75	94	20.7	18.3	11	35	64	91	18.5	16.2	28	41	24
60	72	93	20.5	18.2	13	35	61	90	18.3	16.1	29	42	26
70	70	92	20.4	18.1	15	36	58	89	18.2	15.9	29	43	28
80	67	92	20.3	18.0	17	37	55	87	18.1	15.8	30	43	30
			ALTITUDE		4500 ft	1372 M	BP 644 mmHg	(MTHb + COHb) = 1					
20	82	95	21.0	18.6	4	32	71	93	18.8	16.5	26	39	18
30	79	94	20.8	18.5	6	33	68	92	18.7	16.3	26	40	19
40	77	94	20.7	18.4	8	34	65	91	18.5	16.2	27	40	21
50	74	93	20.6	18.3	10	34	62	90	18.4	16.1	28	41	23
60	71	93	20.5	18.1	12	35	59	89	18.3	16.0	28	42	25
70	68	92	20.3	18.0	14	36	57	88	18.1	15.9	29	43	27
80	65	91	20.2	17.9	15	36	54	87	18.0	15.8	30	43	29
			ALTITUDE		5000 ft	1524 M	BP 632 mmHg	(MTHb + COHb) = 1					
20	81	95	20.9	18.5	4	32	69	92	18.7	16.4	25	39	17
30	78	94	20.8	18.4	6	33	66	92	18.6	16.3	26	39	19
40	75	94	20.6	18.3	7	33	64	91	18.5	16.1	27	40	21
50	72	93	20.5	18.2	9	34	61	90	18.3	16.0	27	41	22
60	70	92	20.4	18.1	11	35	58	89	18.2	15.9	28	42	24
70	67	92	20.2	17.9	12	36	55	87	18.0	15.8	29	42	26
80	64	91	20.1	17.8	14	36	52	86	17.9	15.7	30	43	27
			ALTITUDE		5500 ft	1676 M	BP 621 mmHg	(MTHb + COHb) = 1					
20	79	94	20.8	18.5	4	32	68	92	18.7	16.3	25	38	17
30	77	94	20.7	18.4	5	32	65	91	18.5	16.2	26	39	19
40	74	93	20.6	18.2	7	33	62	90	18.4	16.1	26	40	20
50	71	93	20.4	18.1	8	34	60	89	18.2	16.0	27	41	21
60	68	92	20.3	18.0	10	35	57	88	18.1	15.8	28	41	23
70	66	91	20.2	17.9	11	36	54	87	18.0	15.7	29	42	25
80	63	91	20.0	17.8	13	36	51	85	17.8	15.6	30	43	26