

Spirometry for the Diagnosis and Management of Chronic Obstructive Pulmonary Disease

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Summary

Spirometric testing is one of the oldest clinical tests still in use today. It is a straightforward test that has the patient maximally exhale from total lung capacity. The key measurements are the forced expiratory volume in the first second (FEV₁) and the maximum exhaled volume (vital capacity [VC]). Spirometric testing utility, however, depends heavily upon the quality of equipment, the patient cooperation, and the skill of the technician performing the test. Spirometry should thus be considered a medical test and not simply a vital sign that can be performed by minimally trained personnel. In obstructive lung diseases such as chronic obstructive pulmonary disease (COPD), the characteristic changes in spirometry are a reduction in the FEV₁ with respect to the vital capacity (FEV₁/VC ratio). Using this measurement can diagnose the presence and severity of airway obstruction. This can be used to guide therapies and predict outcomes. Using spirometry to screen for obstructive lung disease, however, can be problematic, and the effect of screening on outcomes has yet to be demonstrated. Key words: spirometry, obstructive airway disease, screening tests, chronic obstructive pulmonary disease management, pulmonary function tests, perioperative risk assessment. [Respir Care 2009;54(8):1050–1057. © 2009 Daedalus Enterprises]

Introduction: The Spirogram

The spirogram was first described in the middle of the 19th century by John Hutchinson,¹ and is thus one of the

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oldest clinical tests still in use today. The maneuver is straightforward: the subject inhales to total lung capacity and then exhales all of the gas that is possible to exhale. The resulting exhaled volume was termed the “vital capacity” (VC) by Hutchinson, and this term has persisted to this day. However, many clinicians today distinguish

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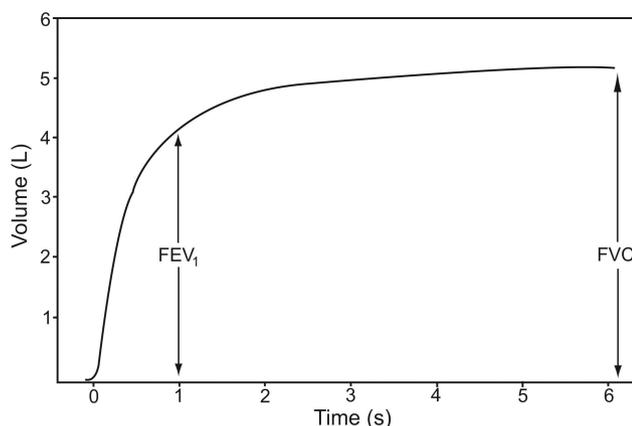


Fig. 1. Spirogram. FEV₁ = forced expiratory volume in the first second. FVC = forced vital capacity.

whether the vital capacity was a “forced” maneuver (ie, the subject exhales with as much velocity as possible) or a “slow” maneuver (ie, the subject exhales at a comfortable rate). In practice, forced and slow VCs are nearly identical in most subjects. However, in some subjects the forced maneuver may be a bit larger, reflecting greater effort, while in other subjects with small-airway collapse the forced VC (FVC) may be smaller than the slow maneuver.²

Over the years, the spirometric maneuver has been analyzed in a variety of ways beyond the measurement of simple VC. Perhaps the most important measurement is that of the volume that could be exhaled in the first second during a forced maneuver—the forced expiratory volume in the first second (FEV₁)^{3,4} (Fig. 1). This value, when referenced to the maximum VC in subjects with good effort, is the current accepted standard for defining the presence or absence of airflow obstruction (see below).⁴⁻⁶ Restrictive and neuromuscular disease categories can also be characterized by spirometric VC and FEV₁ measurements, as described in Table 1.⁷ Other analyses of the spirogram include volumes exhaled over subsequent seconds (eg, the FEV₃ or FEV₆), as well as analyses of flows

during various parts of the expiratory maneuver (see below).

Technical Considerations

In order to standardize the spirometric procedure, the American Thoracic Society and the European Respiratory Society have published a number of technical standards.^{4,5} Equipment and test performance standards are listed in Tables 2 and 3. It is important to realize that using these standardization procedures results in significantly more accurate and reproducible results, and thus these standards should be adopted by all spirometric testing facilities.⁸

In addition to meeting technical standards, spirometric testing facilities must assure that testing personnel be well trained and understand how to do quality spirometry.⁹ This is particularly important because spirometry is heavily patient-dependent and a maximal effort is required. For example, a poor muscular effort will reduce both the VC and the FEV₁, which can mimic either obstructive or restrictive abnormalities (see Table 1). Similarly, a very brief effort may yield nearly identical values for FEV₁ and VC, which can erroneously suggest a normal FEV₁/VC ratio.

These patient-effort and testing personnel issues are of particular concern today in that many organizations are recommending that spirometry be performed in a variety of clinical settings outside the traditional pulmonary function laboratory (eg, physicians’ offices, public screening areas, and health fairs).^{6,10-12} It must be appreciated, however, that in these non-laboratory venues a number of reports have cautioned that significant errors, including both over-diagnosis and under-diagnosis of obstructive and restrictive defects, can occur.¹³⁻¹⁷ One example from the United Kingdom examined a large number of spirometers performed in primary-care physician offices.¹⁵ Although the primary-care physician thought that 90% of these tests were acceptable, an expert review showed that only 64%

Table 1. Vital Capacity and FEV₁ Results in Different Disease Categories

	Vital Capacity*	FEV ₁	FEV ₁ /Vital Capacity
Obstructive Diseases			
COPD	Normal/decreased	Decreased	Decreased
Asthma	Normal/decreased	Decreased†	Decreased†
Restrictive diseases	Decreased	Decreased	Normal
Neuromuscular diseases	Decreased	Decreased	Decreased

* Decreased is defined as outside the lower limit of normal of the reference equations being used. Vital capacity may be normal or may be decreased in obstructive diseases in the presence of air trapping and/or excessive expiratory time requirements.

† Spirometric abnormalities are episodic in asthma.
FEV₁ = forced expiratory volume in the first second
COPD = chronic obstructive pulmonary disease

Table 2. American Thoracic Society/European Respiratory Society Device Standards

Test	Range/Accuracy (BTPS)	Flow Range (L/s)	Time (s)	Resistance and Back Pressure	Test Signal
VC	0.5–8 L ± 3% of reading or ± 0.050 L, whichever is greater	0–14	30	NA	3-L calibration syringe
FVC	0.5–8 L ± 3% of reading or ± 0.050 L, whichever is greater	0–14	15	< 1.5 cm H ₂ O/L/s	24 standard waveforms
FEV ₁	0.5–8 L ± 3% of reading or ± 0.050 L, whichever is greater	0–14	1	< 1.5 cm H ₂ O/L/s	3-L calibration syringe
Time zero	The time point from which all FEV ₁ measurements are taken	0–14	NA	Back extrapolation	24 standard waveforms

BTPS = body temperature and pressure saturated
 NA = not applicable
 VC = vital capacity
 FVC = forced vital capacity
 FEV₁ = forced expiratory volume in the first second
 (Adapted from Reference 3.)

met appropriate acceptability criteria. More importantly, the expert review found that 25% of the patients were subsequently misdiagnosed from these tests.¹⁵

Table 3. American Thoracic Society/European Respiratory Society Spirometry Criteria for Within-Maneuver and Between-Maneuver Acceptability

Within-Maneuver Criteria
Individual spirometry are "acceptable" if:
They are free from artifacts such as:
Cough during the first second of exhalation
Glottis closure that influences the measurement
Early termination or cut-off
Effort that is not maximal throughout
Leak
Obstructed mouthpiece
They have good starts
Extrapolated volume < 5% of FVC or 0.15 L, whichever is greater
They show satisfactory exhalation
Duration of > 6 s (3 s for children) or a plateau in the volume-time curve or if the subject cannot or should not continue to exhale
Between-Maneuver Criteria:
After 3 acceptable spirometry have been obtained, apply the following tests:
The 2 largest values of FVC must be within 0.15 L of each other
The 2 largest values of FEV ₁ must be within 0.15 L of each other
If both of those criteria are met, the test session may be concluded
If both of those criteria are not met, continue testing until:
Both of the criteria are met with analysis of additional acceptable spirometry
or
A total of 8 tests have been performed (optional)
or
The patient/subject cannot or should not continue
Save, as a minimum, the 3 satisfactory maneuvers

FVC = forced vital capacity
 FEV₁ = forced expiratory volume in the first second
 (Adapted from Reference 3.)

In most countries today, pulmonary function laboratories are accredited only for safety and administrative issues, not for test performance standards, equipment standards, quality control, or personnel training. There is, however, growing interest around the world (eg, Australia and New Zealand) in developing more in-depth accreditation programs. This has led to the World Pulmonary Function Laboratory Accreditation Project, which is addressing these issues (<http://www.lungfunction.org/wolfap.html>). Clearly, as spirometry becomes more widespread, it will become increasingly important that appropriate standards be mandated.

Assessing Airway Obstruction With Spirometry

The 2 most common obstructive airway diseases are asthma and chronic obstructive pulmonary disease (COPD). Asthma is defined as an episodic airway inflammatory process, whereas COPD is a more chronic progressive airway inflammatory and scarring process. As noted above, the classic spirometric manifestation of airway obstruction is a reduced FEV₁ with respect to the VC (FEV₁/VC ratio). Conventionally, the larger of the forced or slow VC is recommended for the denominator.³ Many organizations have endorsed the notion that an absolute cutoff of 0.70 for a properly performed FEV₁/VC ratio separates clinically important airway obstruction from normal.^{6,10} This fixed ratio, however, can be misleading, because the normal FEV₁/VC ratio (as defined by being above the lower limit of normal or 95% confidence interval from a reference equation) may exceed 0.75–0.80 in young adults, but then decline to 0.60–0.65 in older subjects.¹⁸ Indeed, the 0.70 value is an accurate threshold for diagnosing airway obstruction only in middle-age subjects. Thus, in the younger age groups the 0.70 cutoff will under-diagnose airway obstruction, whereas in the older age groups it will over-diagnose airway obstruction. Despite this, many organizations noted above have stuck to the 0.70 absolute cutoff recommendation because it is easy to remember and thus perhaps more applicable to large population testing.

Table 4. Effects on Diagnosis With Change to NHANES III From 3 Other Common Reference Equations

Change to NHANES III from:	Crapo (%)	Knudson (%)	Morris (%)
Obstruct to normal	6	15	4
Obstruct to restrict	0.5	6	2
Normal to obstruct	0.01	NA	3
Normal to restrict	5	15	17

NHANES = National Health and Nutrition Examination Survey
(Adapted from Reference 19.)

The selection of reference values is also important. The largest collection of normal spirometric values is from the National Health and Nutrition Survey (NHANES III), performed in the 1990s.⁴ This should probably be considered the accepted standard, as it is the largest collection of normal spirometry on record, and it also accounts for differences in race/ethnicity in African American and Hispanic populations. Use of other prediction equations instead of NHANES III can lead to different interpretation results, as shown in Table 4.¹⁹

Diagnosing airflow obstruction is important. There are many effective interventions in asthma and COPD that improve outcomes. In COPD, for example, smoking cessation, drugs, oxygen, rehabilitation, and surgical options exist for appropriate patients, which improve quality of life, exercise tolerance, health-care cost reductions, and even mortality. This is the rationale behind many organizations urging physician awareness of COPD and documenting it with spirometry.^{6,10-12,20-23} Indeed, a diagnosis of COPD is often erroneously made in clinical practice without spirometry^{22,24} and inappropriate subsequent management results. This emphasizes the importance of using spirometry to confirm that respiratory symptoms suggestive of COPD are actually due to airflow obstruction.

The spirogram can also be analyzed in different ways to describe other airway mechanical characteristics. For example, bronchodilator administration can be given and the change in spirometric values noted.⁵ Several organizations have defined a change in FEV₁ of > 12% under these conditions to represent “bronchodilator responsiveness.”²³ Classically, asthma has bronchodilator responsiveness, whereas COPD does not. However, it has long been known that patients with well established COPD often will have some bronchodilator responsiveness,²⁵ and, conversely, asthmatics, especially if they have taken their bronchodilator therapy before arriving in the pulmonary function laboratory, may have very little airway responsiveness. Whether clinical decisions and clinical plans should be

based on bronchodilator responsiveness is thus unclear and often controversial.

Another use of the spirogram in the evaluation of airway mechanics is the change induced by a bronchoconstrictor, such as methacholine.²⁶ Reductions in FEV₁ after inhalation of graded doses of methacholine can be used to describe airway hyper-responsiveness (conventionally defined as a greater than 20% reduction in FEV₁). Importantly, methacholine challenge testing should usually be reserved for patients with normal spirometry at rest, as serious bronchospasm can be induced in those with known airway obstruction. It is thus not a typical test used to assess fixed airway obstruction such as COPD.

Finally, the spirogram can be plotted as a flow-volume loop, and this allows for more careful analysis of flows at low lung volumes (Fig. 2). It is thought that these expiratory flows at lower lung volumes are largely determined by the collapsing of peripheral non-cartilaginous airways, which function as the rate-limiting step to airflow as the lung empties.² A simple representation of expiratory flows at low lung volumes is the average mid-expiratory flow between 25% and 75% of the VC. Prediction equations for this value, however, are quite “noisy” and probably apply only to measurements taken when the vital capacity is normal. Another characteristic pattern observed with flow-volume loop analysis is the flattening in the inspiratory and expiratory phases that occurs in the presence of upper-airway obstructions.²⁷

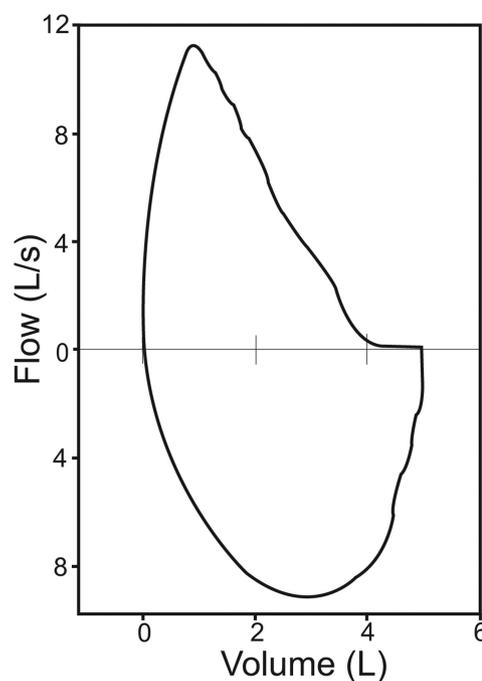


Fig. 2. Flow-volume loop.

Spirometry as a Screening Test to Detect Occult Airflow Obstruction

The lung has a tremendous amount of reserve in it and, therefore, patients with lung disease may not experience symptoms until substantial amounts of lung function are lost. Thus, occult asymptomatic airway obstruction is likely to be present in the general population. Confirming this is the result of the NHANES III study,⁴ which showed that as many as 12% of the asymptomatic population surveyed had evidence of subtle airway obstruction on screening spirometry. Although this was usually mild, it was independently associated with impaired functional or health status.

A key question is whether detecting early, very mild COPD will actually change outcomes, as there is very little specific therapy for occult airway obstruction other than to encourage smoking cessation (which should be done regardless of spirometric abnormalities). The key question is then whether an abnormal spirogram would actually encourage smoking cessation. Conversely, could a normal spirogram in an active smoker actually encourage continuation of the cigarette habit? Some studies suggest that smoking cessation is more common in patients who are told that they have a diagnosis of airway obstruction.²⁸⁻³² This result, however, is not a universal finding.³³⁻³⁵ Moreover, even in the positive studies it is conceivable that the actual impact of spirometry may have been an *increase* in smoking in the subjects with normal spirometry, versus a reduction in smoking in those with abnormal spirometry. The impact of spirometry on smoking cessation is thus still an unanswered question.

Screening tests also have the potential for producing false positive and false negative tests (ie, diagnosing disease when none is present and missing disease when it is present).³⁶ With spirometry, as noted above, these false positive and false negative rates may be dramatically increased if the technical standards are not met, patient cooperation is poor, or technician performance is suboptimal. False positive tests can lead to unnecessary diagnostic testing and stress on the patient. Conversely, false negatives give patients a false sense of being disease-free. Smoking injury occurs over decades and, thus, a normal spirogram at age 20 or 30 does not necessarily mean that there will not be substantial lung damage later in life.³⁷ Moreover, a negative spirogram in a smoker does not mean that other cigarette-related diseases or risk of disease are not present (eg, lung cancer or cardiovascular disease).

A recent Agency for Health Care Research and Quality evidence-based review project³⁸ concluded that if 10,000 current smokers over 40 years old received spirometric screening, 207 would qualify for inhaled therapies (2%), which would result in 12 fewer initial exacerbations. Put another way, the number needed to screen to prevent one

initial exacerbation is 833. Given the enormous costs associated with such a massive screening program and the very limited benefit of preventing only an initial exacerbation, the Agency for Health Care Research and Quality concluded that screening spirometry was not cost-effective. Of note is that this analysis did not factor in costs of assessing the many false positive spirometric tests that would be expected—an additional reason to be cautious about mass screening.

Taken together, these data would suggest that large spirometric screening programs of asymptomatic subjects, especially with testing programs of low quality, are not wise. On the other hand, well designed programs focusing on high-risk subjects (eg, smokers) with symptoms could be useful in identifying COPD patients who would benefit from more in-depth evaluation and management.³⁹⁻⁴³

Using Spirometry to Stage COPD and to Guide Therapies

The Global Initiative for Chronic Obstructive Lung Disease (GOLD) has proposed 4 stages of COPD, based upon spirometric testing.⁶ These are an FEV₁/VC ratio < 0.70 and: FEV₁ > 80% predicted (stage I, mild), FEV₁ of 50–80% predicted (stage II, moderate), FEV₁ of 30–50% predicted (stage III, severe), and FEV₁ < 30% predicted (stage IV, very severe). Based on these staging criteria, stepwise approaches to therapy are recommended and are illustrated in Figure 3. This staged approach is a very logical framework to guide therapy for patients with COPD.

The FEV₁ can also be used to guide other therapies in COPD. As a marker of severity of lung disease it can be helpful in guiding decisions for surgeries such as lung-volume-reduction surgery. The National Emphysema Treatment Trial demonstrated, for example, that if the FEV₁ is < 20% predicted, lung-volume-reduction surgery is inappropriate and associated with a high surgical mortality.⁴⁴ In assessing other operative risks, spirometry can be used to diagnose and stage COPD as well as to quantify restrictive and neuromuscular defects (see Table 1). These lung diseases are clearly risk factors for postoperative pulmonary complications, and knowing the degree of impairment can help assess the magnitude of the risk. For example, lung-disease patients with mild-moderate impairment (FEV₁ of 61–79% predicted) had a 4-fold risk of postoperative pulmonary complications over non-lung-disease patients, but this risk increased to over 15-fold when the FEV₁ was less than 61% predicted.⁴⁵ However, as noted for COPD screening above, routine spirometry as a preoperative procedure in unselected patients is probably not cost-effective.⁴⁶

Spirometry can also be a useful tool in following other patients as well. This is particularly true in following patients on chemotherapy or other lung-toxic drugs, where

New	0: At Risk	I: Mild	II: Moderate	III: Severe	IV: Very Severe
Characteristics	<ul style="list-style-type: none"> Chronic symptoms Exposure to risk factors Normal spirometry 	<ul style="list-style-type: none"> FEV₁/FVC < 70% FEV₁ ≥ 80% With or without symptoms 	<ul style="list-style-type: none"> FEV₁/FVC < 70% 50% ≤ FEV₁ < 80% With or without symptoms 	<ul style="list-style-type: none"> FEV₁/FVC < 70% 30% ≤ FEV₁ < 50% With or without symptoms 	<ul style="list-style-type: none"> FEV₁/FVC < 70% FEV₁ ≥ 30% or presence of chronic respiratory failure or right heart failure
Avoidance of risk factor(s); influenza vaccination					
Add short-acting bronchodilator when needed					
Add regular treatment with one or more long-acting bronchodilators Add rehabilitation					
Add inhaled glucocorticosteroids if repeated exacerbations					
Add long-term oxygen if chronic respiratory failure Consider surgical treatments					

Fig. 3. System for staging and management of chronic obstructive pulmonary disease (COPD) by the Global Initiative for Chronic Obstructive Lung Disease (GOLD). FEV₁ = forced expiratory volume in the first second. FVC = forced vital capacity. (From Reference 6)

reductions in VC may be a very early sign of drug toxicity. Another example is in the follow-up of lung transplantation, where one of the earlier signs of rejection is a reduction in FEV₁ and VC.

Spirometry to Predict Quality of Life, Exacerbations, and Survival in COPD

Not surprisingly, the FEV₁ correlates with exercise capacity, activities of daily living, and quality of life in COPD patients.^{47,48} Perhaps more importantly, multiple studies have correlated FEV₁ or FEV₁ decline as strong predictors of the risk of COPD exacerbation.⁴⁹⁻⁵¹ This emphasizes the need to recognize these patients, since COPD exacerbations are the single most expensive aspect of COPD care, and multiple effective therapeutic interventions (eg, drugs, rehabilitation) are available to reduce exacerbations. Finally, the FEV₁ has been known for decades to correlate with mortality, not only from COPD, but from other chronic diseases as well.⁵²⁻⁵⁶

The mortality-prediction capability for spirometry is strengthened when the FEV₁ is incorporated into the BODE index, a 4-component assessment with scores of 1–4 for each component.^{57,58} The 4 components are body mass index (B), airway obstruction from FEV₁ (O), dyspnea score from the Medical Research Council questionnaire (D), and exercise capability from the 6-min walk distance (E) (Table 5). The 4 component scores are added together for the final BODE score. BODE scores of > 7 have a 4-year mortality of 80–90%, compared to patients with BODE scores of 0–2 (20–30% 4-year mortality), BODE scores of 3–4 (50–60% 4-year mortality), and BODE scores

of 5–6 (70–80% 4-year mortality). Because BODE scores are easy to obtain, they have potential utility in assessing risk and changes in that risk from various interventions.

Spirometry and the Respiratory Therapist

The respiratory therapist (RT) occupies a pivotal role in applying spirometry to disease management in patients with COPD. At the technical level it is the RT who has the skill to assure both quality testing as well as appropriate diagnostic algorithms. Indeed, in the general practice environment it is often the RT who probably has the best insight into spirometric interpretation. In the stable patient with COPD (ie, at least 4–8 weeks removed from an exacerbation), RTs should emphasize to other caregivers the importance of baseline spirometry in staging and man-

Table 5. BODE Score

	BODE Score			
	0	1	2	3
FEV ₁ % predicted	> 65	50–65	35–49	< 35
Dyspnea: MRC	0–1	2	3	4
6MWD (m)	> 350	250–349	150–249	< 149
BMI (kg/m ²)	> 21	< 21	NA	NA

FEV₁ = forced expiratory volume in the first second
MRC = Medical Research Council
6MWD = 6-min walk distance
BMI = body mass index
NA = not applicable
Data from Reference 57.

aging patients as well as for predicting outcomes. Finally, if spirometry is to be used as a tool to encourage smoking cessation, it is incumbent for the RT to point out the implications of continued smoking in those with abnormal spirometry. It is perhaps even more important for the RT to emphasize that even in the presence of normal spirometry, smoking is a lifelong risk for future COPD manifestations as well as for numerous other cardiopulmonary disorders.

Summary

Spirometric testing has stood the test of time. Spirometric testing, however, depends heavily upon the quality of equipment, the patient cooperation, and the skill of the technician performing the test. Spirometry should thus be considered a medical test and not simply a vital sign that anyone can perform. In obstructive lung disease the characteristic changes in spirometry are a reduction in FEV₁ with respect to VC. Using this measurement, clinicians can diagnose the presence and severity of airway obstruction. This can be used to guide therapies and predict outcomes. Using spirometry to screen for obstructive lung disease in asymptomatic populations, however, can be problematic, and the effects of screening on outcomes have yet to be demonstrated.

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