REVIEW

FEYROUZ AL-ASHKAR, MD
Department of General Internal Medicine, The Cleveland Clinic

REENA MEHRA, MD
Department of Pulmonary and Critical Care Medicine, University Hospitals, Cleveland

PETER J. MAZZONE, MD, MPH
Department of Pulmonary and Critical Care Medicine, The Cleveland Clinic

Interpreting pulmonary function tests: Recognize the pattern, and the diagnosis will follow

ABSTRACT

When interpreting pulmonary function tests, one should first try to determine the pattern of abnormality: is it obstructive, restrictive, or normal? Pulmonary function tests cannot by themselves distinguish among the potential causes of abnormalities, and must be interpreted in light of the patient's history, physical examination, and ancillary studies. Once a pattern is recognized, the diagnosis will often follow.

KEY POINTS

Every clinician should have an organized approach to interpreting pulmonary function tests that will allow him or her to recognize and quantitate abnormalities.

Before interpreting the results, one should ascertain that the test was acceptable and reproducible and that the patient's demographic data are correct.

Pattern recognition is key. A low FEV_1/FVC ratio (the forced expiratory volume in 1 second divided by the forced vital capacity) indicates an obstructive pattern, whereas a normal value indicates either a restrictive or a normal pattern.

If the FEV_1/FVC ratio is normal, a low forced vital capacity value indicates a restrictive pattern, whereas a normal value indicates a normal pattern.

Pulmonary function tests are not generally indicated in patients without symptoms, and they may be confusing when nonpulmonary diseases that affect the pulmonary system are active (eg, congestive heart failure).

THE MAJOR LIMITATION of pulmonary function tests is in how they are interpreted. They can be used to identify the pattern and severity of a physiologic abnormality, but used alone, they generally cannot distinguish among the potential causes of the abnormalities.

Thus, pulmonary function tests must be interpreted in the context of a proper history, physical examination, and ancillary diagnostic tests. Once a pattern is recognized (obstructive, restrictive, or normal) and its severity measured, that information, combined with other patient data, often leads to a diagnosis.

In this article we will provide an overview of basic pulmonary function tests and an algorithm for using and interpreting them, and then we use three cases to explain how to use these tests to identify the pattern of respiratory dysfunction, *then* make the diagnosis.

INDICATIONS FOR PULMONARY FUNCTION TESTING

Pulmonary function tests are ordered:

- To evaluate symptoms and signs of lung disease (eg, cough, dyspnea, cyanosis, wheezing, hyperinflation, hypoxemia, hypercapnia)[1,2]
- To assess the progression of lung disease
- To monitor the effectiveness of therapy
- To evaluate preoperative patients in selected situations[1,2]
- To screen people at risk of pulmonary disease such as smokers or people with occupational exposure to toxic substances in occupational surveys.

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TABLE 1

Key abbreviations and definitions used in pulmonary function tests

DLCO	Diffusing capacity of the lung; the capacity of the lungs to transfer carbon monoxide (mL/min/mm Hg)
DLCOc	The DLCO adjusted for hemoglobin (mL/min/mm Hg)
DLVA	The DLCO adjusted for volume (mL/min/mm Hg/L)
DLVC	The DLCO adjusted for both volume and hemoglobin (mL/min/mm Hg/L)
ERV	Expiratory reserve volume; the maximum volume of air that can be exhaled from the end-expiratory tidal position (L)
FET	Forced expiratory time; the amount of time the patient exhales during the FVC maneuver (seconds)
FEV_1	Forced expiratory volume in 1 second; volume of air forcibly expired from a maximum inspiratory effort in the first second (L)
FEV_1/FVC ratio	Ratio of FEV_1 to FVC
FRC	Functional residual capacity; the volume of air in the lungs following a tidal volume exhalation = ERV + RV (L)
FVC	Forced vital capacity; the total volume that can be forcefully expired from a maximum inspiratory effort (L)
IC	Inspiratory capacity; the maximum volume of air that can be inhaled from tidal volume end-expiratory level; the sum of IRV and VT (L)
IRV	Inspiratory reserve volume; the maximum volume of air that can be inhaled from the end-inspiratory tidal position (L)
LLN	Lower limit of normal; the lowest value expected for a person of the same age, gender, and height with normal lung function
PEF	Peak expiratory flow; the highest forced expiratory flow (L/second)
RV	Residual volume; the volume of air that remains in the lungs after maximal exhalation (L)
TLC	Total lung capacity; the total volume of air in the lungs at full inhalation; the sum of all volume compartments (IC + FRC or IRV + V_T + ERV + RV) (L)
TV or VT	Tidal volume; the volume of air that is inhaled or exhaled with each breath when a person is breathing at rest (L)
VC	Vital capacity; the maximum volume of air that can be exhaled starting from maximum inspiration, TLC (L) can be measured either as slow vital capacity (SVC) or forced vital capacity (FVC)

The major limitation of pulmonary function tests is in how they are interpreted

- To monitor for the potentially toxic effects of certain drugs or chemicals (eg, amiodarone, beryllium)

Pulmonary function tests are *not* otherwise indicated in patients without symptoms, and they may be confusing when nonpulmonary diseases that affect the pulmonary system are active (eg, congestive heart failure).

COMPONENTS OF PULMONARY FUNCTION TESTS

Spirometry

Spirometry is the measurement of the air moving in and out of the lungs during various respiratory maneuvers.[2] It allows one to determine how much air can be inhaled and exhaled, and how fast.

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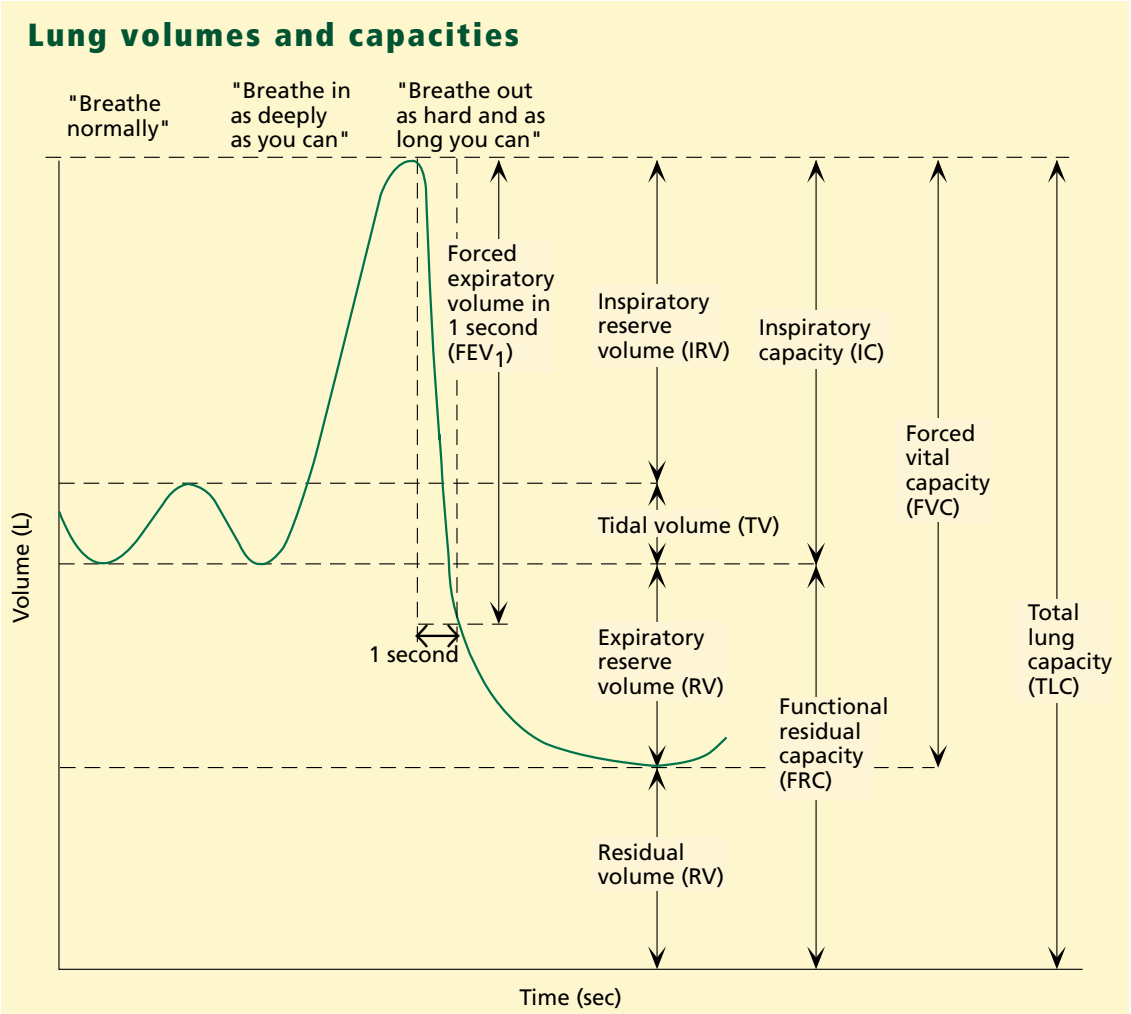

FIGURE 1. Lung volumes and capacities depicted on a volume-time spirogram. The most important values are the forced vital capacity (FVC), the forced expiratory volume in 1 second (FEV_1), and the FEV_1/FVC ratio. Spirometry cannot measure the residual volume or the total lung capacity.

The three most important measures are the:
- **FVC**
- **FEV_1**
- **FEV_1/FVC ratio**

The components of the respiratory cycle are labeled as lung volumes and lung capacities (a capacity is the sum of one or more volumes; TABLE 1, FIGURE 1). We are mainly concerned with three of these measures:

- **The forced vital capacity (FVC).** A spirometric maneuver begins with the patient inhaling as deeply as he or she can. Then the patient exhales as long and as forcefully as possible; the amount exhaled in this manner is the FVC.
- **The forced expiratory volume in 1 second (FEV_1)** is the amount of air exhaled during the first second of the FVC maneuver. It tends to be lower in diseases that obstruct the airway, such as asthma or emphysema.
- **The FEV_1/FVC ratio** is used to determine if the pattern is obstructive, restrictive, or normal.

Diffusing capacity

The diffusing capacity is a measure of the ability of the lungs to transfer gas.[3,4]

Diffusion in the lungs is most efficient when the surface area for gas transfer is high and the blood is readily able to accept the gas being transferred. It is thus decreased in:

- Conditions that minimize the ability of

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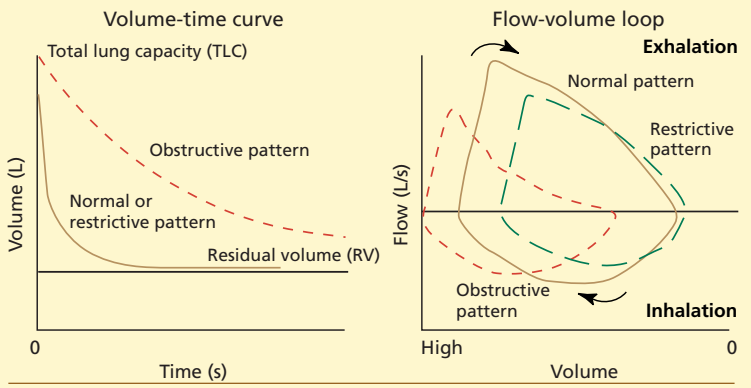

FIGURE 2. Volume-time curve and flow-volume curve

the blood to accept and bind the gas that is diffusing (eg, anemia)

- Conditions that decrease the surface area of the alveolar-capillary membrane (eg, emphysema, pulmonary embolism)
- To a smaller degree, conditions that alter the membrane's permeability or increase its thickness (eg, pulmonary fibrosis).

The gas used to test the diffusing capacity must be more soluble in blood than in lung tissue. Ideally, the amount of gas entering the blood should be limited by the lungs' ability to transfer it and not by lung perfusion (ie, the gas must avidly bind to hemoglobin). Carbon monoxide is the gas used, as it most closely meets these requirements.

Pulmonary function tests may be confusing in nonpulmonary diseases such as heart failure

Residual volume, total lung capacity

Even after one exhales as long and as hard as possible, some air remains in the lungs; this is called the *residual volume*. The residual volume plus the FVC equals the *total lung capacity*.

The residual volume (and hence the total lung capacity) cannot be measured by spirometry. Rather, they must be measured by special tests that require the patient either to breathe an inert gas such as helium (the concentration of which is measured in the expired air, from which the residual volume is calculated) or to sit in an airtight booth in which the pressure is measured as he or she breathes.

These measurements (commonly called "static lung volumes" or simply "volumes") add to the information gained from spirometry. For obstructive diseases, measurement of the residual volume and total lung capacity can demonstrate air trapping and hyperinflation. For restrictive diseases, the total lung capacity is needed to confirm true restriction and better quantitate the degree of restriction.[5]

OUR APPROACH TO INTERPRETING PULMONARY FUNCTION TESTS

First, confirm the patient's demographic data

Test results are given as measured values and as percents of predicted values.

The predicted values and lower limits of normal have been determined in population studies of people without physiologic lung impairment. Regression equations have been developed that include the person's age, height, and sex as variables (although debate exists as to which regression equations are most accurate).[6]

Each patient's predicted values therefore depend on his or her age, height, and sex. For example, the predicted values for an 80-year-old man who is 6 feet tall are lower than those of a 50-year-old man who is 6 feet tall. In practice, the physician or technician who performs the test enters the patient's demographic data into a computer. Although clerical mistakes are rare, the physician who interprets the test should double-check this information, which should be included in the test report. If the patient's demographic data are not accurate, the interpretation of the results will be affected.

Next, evaluate the test for acceptability and reproducibility

Criteria for acceptability and reproducibility are established by the American Thoracic Society.[7]

In general, an FVC maneuver is acceptable if the patient has made a good effort. An effort is considered good when there is a rapid increase in air flow at the start of exhalation. A complete maneuver requires at least 6 seconds of exhalation ending with a plateau in flow (ie, no further air is being blown out).

A flow-time curve and flow-volume loop are usually included with the report to allow one to visualize the rapid rise and the plateau in flow over time and over lung volumes. In a

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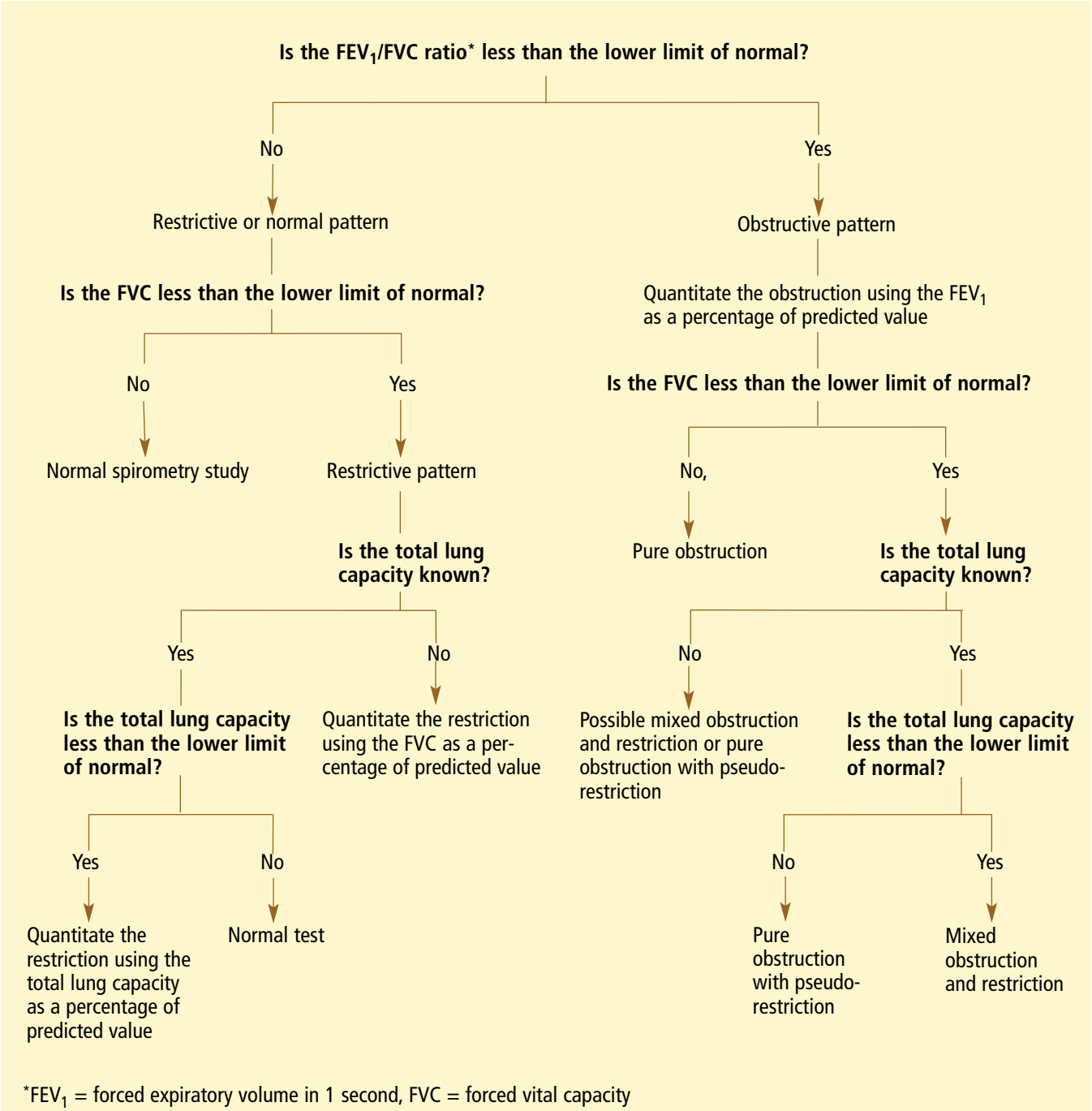

FIGURE 3. Flow chart for rapid interpretation of pulmonary function tests

proper FVC maneuver, flow rates should be at their highest near the start of exhalation and should decline through the end of exhalation. This is graphed in the volume-time curve (FIGURE 2).

Similarly, flow rates are highest near the total lung capacity (where the FVC maneuver begins) and they decline until the residual volume (where the FVC maneuver ends). This is graphed as the flow-volume loop (FIGURE 2).

The test is repeated at least three times. To meet reproducibility criteria, all three

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TABLE 2

Obstructive and restrictive patterns

MEASUREMENT	OBSTRUCTIVE PATTERN	RESTRICTIVE PATTERN
Forced vital capacity (FVC)	Decreased or normal	Decreased
Forced expiratory volume in 1 second (FEV_1)	Decreased	Decreased or normal
FEV_1/FVC ratio	Decreased	Normal
Total lung capacity (TLC)	Normal or increased	Decreased

FEV_1 measurements must be within 200 mL of each other and all three FVC measurements must be within 200 mL of each other. The test with the greatest sum of the FEV_1 and the FVC is reported.

The results may vary if the subject does not give his or her best effort, cannot understand the instructions (owing to a language barrier or hearing impairment), or has pain that is accentuated with the maneuvers. Results that are not reproducible may not accurately reflect the patient's true lung physiology.

Use a systematic approach to interpreting the results

FIGURE 3 is our suggested approach to interpreting the results. The approach involves recognizing the pattern and then classifying the severity of the condition.

Is the pattern obstructive, restrictive, or normal? The first step is to assess the FEV_1/FVC ratio. If this ratio is less than the lower limit of normal for the patient (included with the test report), an obstructive defect is present (ie, the FEV_1 has fallen to a greater degree than the FVC).

If this ratio is greater than the lower limit of normal, then either the spirometry test is normal or a restrictive defect is present. In this situation, if only spirometry is available, the next step is to look at the FVC. If the FVC is less than the lower limit of normal, a restrictive defect is suggested. The total lung capacity (if this was measured) can confirm the presence of restriction if this value is less than the predicted lower limit of normal.

TABLE 2 compares obstructive and restrictive lung patterns.[8]

Spirometry is frequently repeated after giving a bronchodilator. If either the FEV_1 or the FVC increases by at least 12% and by at least 200 mL from the prebronchodilator values, then the patient is said to have a significant bronchodilator response.[9]

How severe is the defect? To quantify the degree of obstruction, the clinician needs to note the patient's FEV_1 as a percentage of the predicted FEV_1 (**TABLE 3**) Similarly, to quantify the degree of restriction, one should note either the patient's FVC or the total lung capacity as a percentage of the respective predicted value.

If the FEV_1/FVC ratio is low, an obstructive defect is present

CASE 1: DYSPNEA WITH COUGH AND WHEEZING

A 51-year-old woman presents for evaluation of shortness of breath, cough, and wheezing, especially in the summer. Her symptoms are relieved with albuterol, salmeterol, and fluticasone inhalers. She does not smoke. **TABLE 4** shows her spirometry values.

1 Which of the following patterns is present?

- ❑ Obstructive pattern without response to bronchodilators
- ❑ Restrictive pattern
- ❑ Obstructive pattern with response to bronchodilators

Using **FIGURE 3** as a guide, the first step is to assess the FEV_1/FVC ratio. The ratio of 58% is clearly low. Therefore, the spirometry data reveal an obstructive pattern.

The pattern is not restrictive, since the

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TABLE 3

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TABLE 4

Case 1: A 51-year-old woman with shortness of breath, coughing, and wheezing

	LOWER LIMIT OF NORMAL	PRE-BRONCHO-DILATOR	% OF PREDICTED VALUE	POST-BRONCHO-DILATOR	% CHANGE
Forced vital capacity (FVC)	2.24 L	2.42 L	83%	2.72 L	12%
Forced expiratory volume in 1 second (FEV_1)	1.86 L	1.52 L	63%	2.05 L	34%
FEV_1/FVC ratio	73.4%	58.2%		75.3%	29%
Forced expiratory time		11.2 sec		10.7 sec	

Air trapping in severe obstruction can cause a pattern of pseudo-restriction

FEV_1/FVC ratio is low and the FVC is normal. In a restrictive pattern, the FEV_1/FVC ratio is typically normal or high and the FVC is typically low.

2 What is the severity of this patient's defect?

- ❑ Mild
- ❑ Moderate
- ❑ Severe

TABLE 3 classifies the severity of the defect. Since this patient's FEV_1 lies between 60% and 69% of the predicted value, the degree of obstruction is classified as moderate. It is an obstructive pattern with a good bronchodilator response, since the absolute change in FEV_1 after bronchodilator administration is greater than 12% and 200 mL.

The clinical presentation and spirometry data strongly suggest asthma.

Pulmonary function testing pearl: Distinguish a mixed pattern vs air trapping

Once you have determined that the spirometry data are compatible with obstruction and you have quantitated the degree of obstruction on the basis of the FEV_1 percent of predicted, you should look at the FVC.

If the FVC is less than the lower limit of normal, then two possibilities exist. The first is that there is a mixed pattern with both an obstructive and a restrictive component. The second is that the obstruction is very severe and has led to significant air trapping.

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Air trapping will increase the residual volume so that it takes up a greater percentage of the total lung capacity. If the residual volume increases enough, it will encroach on the air in the lung that can be exhaled and may lower the FVC below the lower limit of normal. This spirometry pattern is known as *pseudorestriction* (FIGURE 4).

To distinguish between these two possibilities, measure the residual volume and total lung capacity. If there is a mixed pattern with obstructive and restrictive components, the total lung capacity will be decreased. If air trapping is the cause of the low FVC, then the total lung capacity will be normal or elevated and the residual volume will be significantly increased.

CASE 2: DYSPNEA WITHOUT COUGH OR WHEEZING

A 68-year-old woman presents for evaluation of shortness of breath without cough or wheezing. She has systemic lupus erythematosus (for which she takes prednisone and methotrexate) and hypertension (for which she takes metoprolol and hydrochlorothiazide). Her oxygen saturation is 94% by pulse oximetry while breathing room air. Her hemoglobin concentration is 12.3 g/dL. TABLE 5 shows the results of her pulmonary function tests.

3 Which of the following best describes the pattern seen on this patient's pulmonary function tests?

- ❑ Obstructive pattern with suspicion of emphysema
- ❑ Restrictive pattern
- ❑ Obstructive pattern without emphysema

The patient's FEV_1/FVC ratio (88.6%) is normal. Therefore, the pattern could either be normal or restrictive (TABLE 2). However, since the patient's FVC (1.85 L, 60% of predicted) is lower than the lower limit of normal (2.39 L), a restrictive pattern is present. The patient's diminished total lung capacity confirms the presence of restriction.

4 What is the severity of this patient's defect?

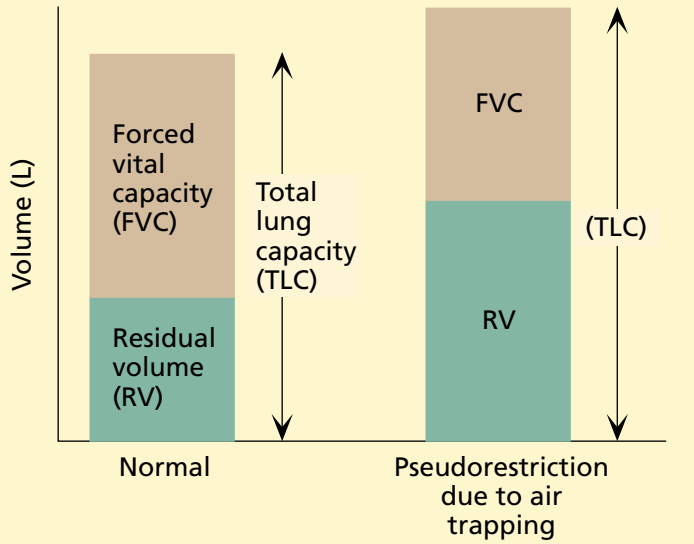

FIGURE 4. Normal spirometry vs pseudorestriction (obstructive pattern with air trapping). Note that in pseudorestriction the forced vital capacity (FVC) is smaller, suggesting restriction. However, the TLC is increased and thus there is no restriction. The smaller FVC is due to air trapping resulting in an increased residual volume.

- ❑ Mild
- ❑ Moderate
- ❑ Moderately severe
- ❑ Severe

Based on TABLE 3, the defect, with an FVC of 60% and a total lung capacity of 53% of predicted, is moderately severe. An obstructive pattern is not present since the FEV_1/FVC ratio is normal. Emphysema has an obstructive pattern on pulmonary function tests; therefore, it is unlikely to be present in this case.

The clinical evaluation, including imaging studies and pulmonary function testing, strongly suggests interstitial lung disease related to her lupus.

Pulmonary function testing pearl: Distinguish parenchymal vs extraparenchymal causes of restriction

A restrictive pattern seen on pulmonary function testing may be due to causes inside or outside the lung parenchyma.

Pulmonary parenchymal causes include

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TABLE 5

Case 2: A 68-year-old woman with shortness of breath, but no cough or wheezing

	LOWER LIMIT OF NORMAL	PATIENT'S VALUE	% OF PREDICTED
Forced vital capacity (FVC)	2.39 L	1.85 L	60%
Forced expiratory volume in 1 second (FEV_1)	1.80 L	1.64	70%
FEV_1/FVC ratio	67.3%	88.6%	
Forced expiratory time (FET)		9.2 sec	
Residual volume (RV)	1.4 L	0.83 L	38%
Total lung capacity (TLC)	4.12 L	2.74 L	53%
Diffusing capacity (DLCO)	14.7 mL/min/mm Hg	8.73 mL/min/mm Hg	38%
Adjusted diffusing capacity			
DLVA	3.37 mL/min/mm Hg/L	3.30 mL/min/mm Hg/L	73%
DLCOc	14.7 mL/min/mm Hg	9.05 mL/min/mm Hg	46%
DLVC	3.37 mL/min/mm Hg/L	3.42 mL/min/mm Hg/L	76%

diseases such as pulmonary fibrosis, in which abnormalities of the lungs themselves result in restriction. Extraparenchymal causes of restriction include obesity, neuromuscular diseases, chest wall deformities, and large pleural effusions, which may impair a person's ability to fully inflate the lungs.

Extra-parenchymal causes of restriction:
- **Obesity**
- **Neuromuscular disease**
- **Chest wall deformities**
- **Large pleural effusions**

The diffusing capacity of the lung (DLCO) can be used to distinguish between these categories. If the DLCO is still below the lower limit of normal after being adjusted for the lung volume (ie, the DLVA), hemoglobin level (ie, the DLCOc), or both (ie, the DLVc), then parenchymal disease is likely. If normal, it suggests that the cause of restriction is extraparenchymal.

To determine which parenchymal or extraparenchymal cause of restriction is present requires a complete clinical evaluation.

CASE 3: PROGRESSIVE DYSPNEA

A 68-year-old woman presents for evaluation of progressive shortness of breath. She describes 18 months of gradually increasing dyspnea on exertion. She has not noted any prominent cough, wheezing, chest pain, lightheadedness, or edema. Her review of systems is positive only for cold fingers and mild joint pains. She has never smoked and has no other medical history. Her only medication is hormone replacement therapy. **TABLE 6** shows her pulmonary function test results.

5 Which of the following are potential causes of this pattern?

- ❑ Anemia
- ❑ Pulmonary arterial hypertension
- ❑ Chronic thromboembolic disease
- ❑ All of the above

The FEV_1/FVC ratio is normal, leaving us with either a restrictive or a normal pattern.

As both the FVC and total lung capacity are normal, we conclude that the spirometry and lung volumes are normal. This suggests that the airways and lung parenchyma are functioning normally. We notice, however, that the diffusing capacity is significantly reduced, and that the value remains low when corrected for lung volumes (ie, the DLVA).

This pattern may be seen in a few situations. In anemia, the number of hemoglobin molecules to which carbon monoxide can bind is reduced, decreasing the ability of the lungs to transfer carbon monoxide to the blood, thus

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TABLE 6

Case 3: A 68-year-old woman with progressive shortness of breath

	LOWER LIMIT OF NORMAL	PATIENT'S VALUE	% OF PREDICTED
Forced vital capacity (FVC)	2.07 L	2.63 L	96%
Forced expiratory volume in 1 second (FEV_1)	1.56 L	2.15 L	101%
FEV_1/FVC ratio	68.3%	81.7%	
Forced expiratory time (FET)		8.13 sec	
Residual volume (RV)	1.30 L	1.77 L	85%
Total lung capacity (TLC)	3.77 L	4.01 L	83%
Diffusing capacity (DLCO)	16.4 mL/min/mm Hg	9.29 mL/min/mm Hg	43%
Adjusted diffusing capacity (DLVA)	3.34 mL/min/mm Hg/L	2.65 mL/min/mm Hg/L	59%

lowering the diffusing capacity without affecting any of the lung volumes or capacities. Pulmonary vascular diseases, such as pulmonary arterial hypertension and chronic thromboembolic disease, may also cause an isolated decrease in the diffusing capacity.

The clinical, radiographic, and pulmonary function information suggest pulmonary hypertension. Echocardiography and subsequent right heart catheterization confirm this diagnosis.

CONCLUSIONS

These cases underscore one of the chief messages in this article, that when interpreting pulmonary function tests, the first goal is to recognize the pattern of physiologic impairment, not to make a diagnosis. Once the pattern is recognized, the astute physician has important information to make the diagnosis and treat a pulmonary problem.

The first goal is to recognize the pattern, not to make a diagnosis

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ADDRESS: *Peter J. Mazzone, MD, FRCP, MPH, Department of Pulmonary and Critical Care Medicine, A90, The Cleveland Clinic Foundation, 9500 Euclid Avenue, Cleveland, OH 44195; e-mail mazzonp@ccf.org.*

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