Pulmonary Function Tests

Spirometry
Spirometry measures the amount and rate of air a person breathes in order to diagnose illness or determine progress in treatment.
COPD

• The most common respiratory disease
• One of the leading causes of death in the United States

*spirometry* is the preferred test for the diagnosis of COPD...

... the results must be correlated carefully with clinical and rentgenographic data for optimal clinical application.

(Barreido TJ, Perillo I: An Approach to Interpreting Spirometry, AmFamPhysician2004;69)
The maneuver may be performed

- in **a forceful manner** to generate
  a forced vital capacity (**FVC**)  

- in **a more relaxed manner** to generate
  a slow vital capacity (**SVC**)
- (SLOW) VITAL CAPACITY TEST

- FORCED VITAL CAPACITY TEST
In **an expiratory tests** we measure

- **how much** air the patient can exhale after a maximum inspiration (SVC test or FVC test)
  
  and

- **how fast** they can exhale it (FVC test)
(Slow) VITAL CAPACITY TEST

VC - Maximum volume of air expired from the point of maximum inspiration

Figure 19-1 The subdivisions of the lung volume. The term capacity is applied to a subdivision composed of two or more volumes. The definitions of these subdivisions are found in Table 19-1.
MEASUREMENT OF RV (FRC, TLC)

- impossible by a direct method /spirometry/!

MEASUREMENT OF RV (FRC, TLC) -

INDIRECT!

(Closed-Circuit Helium Method)
Is the test normal?

• Effects of physical characteristics:
  - Sex
  - Age
  - Height
  - Weigh

• Sporting activity
Is the Test Normal?

- The patient’s results are compared to an average healthy subject of the same age, height, gender, and ethnic group (predicted normal value)
Is the Test Normal?

Parameters below the Lower Limits of Normal (LLN) indicate a possible lung disease

What is LLN?

Fixed value for the lower limit of normal

80% of predicted

\[(F)VC \geq 80\% \text{ of predicted} - \text{Normal}\]
What is the Range? - Setting the Threshold

- "Publications on reference equations should include explicit definitions of the upper and lower limits of the normal range, or provide information to allow the reader to calculate a lower range”

- "The ATS has recommended the use of lower limits of normal instead of the 80% of predicted for setting the threshold that defines abnormal test results”. → In normal spirometry, SVC, FVC, FEV1, and FEV1-to-FVC ratio are above the lower limit of normal.

- The practice of using 80% predicted as a fixed value for the lower limit of normal may be acceptable in children, but can lead to important errors when interpreting lung function in adults. The practice of using 0.70 as a lower limit of the FEV1/FVC ratio results in a significant number of false-positive results in males aged >40 yrs and females > 50 yrs, as well as in a risk of overdiagnosis of chronic obstructive pulmonary diseases (COPD) in asymptomatic elderly never-smokers.

- Because there is no absolute cut-off point for what is normal in biologic systems, an arbitrary statistical approach is widely used to define the lowest 5% of the population as abnormal.

- The ATS recommends using the concept of lower limit of normal by identifying the lowest 5% of a population (below the 5th percentile), or patients that fall outside the limits of 1.645 SD from the mean. This value may be calculated by multiplying 1.645 times the standard error of estimate (1.645 × SEE).
Is the Test Normal?

Parameters below the Lower Limits of Normal (LLN) indicate a possible lung disease

What is LLN?

1. Fixed value for the lower limit of normal
   
   80% of predicted

   \((F)VC \geq 80\%\) of predicted - Normal

2. Values below the 5\textsuperscript{th} percentile
SPIROMETRY

Spirometry Training Program

Spirometry Reference Value Calculator
Enter Age, Height, Gender and Race. To see Percent Predicted, you must enter observed FVC, FEV₁, and FEF25-75% values in the appropriate boxes. Click Calculate to calculate the predicted values.

Reference Source: Hankinson-1999
Gender: Female
Race: Caucasian
Age: 75
Height: 165 cm

Optional Observed Values Below - Enter to calculate Percent Predicted
FVC (L): 2.25
FEV₁ (L): 1.85
FEF25-75% (L/s): 2.00
FEV₁/FVC%: 82.2

Calculated Values

<table>
<thead>
<tr>
<th></th>
<th>FVC (L)</th>
<th>FEV₁ (L)</th>
<th>FEV₁/FVC%</th>
<th>FEF25-75% (L/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predicted</td>
<td>2.93</td>
<td>2.20</td>
<td>74.9%</td>
<td>1.71</td>
</tr>
<tr>
<td>Percent Predicted</td>
<td>76.8%</td>
<td>84.0%</td>
<td>109.8%</td>
<td>116.6%</td>
</tr>
<tr>
<td>Lower Limit of Normal</td>
<td>2.22</td>
<td>1.60</td>
<td>65.1%</td>
<td>0.44</td>
</tr>
</tbody>
</table>

* Predicted are for race selected above — no race correction factor needed.

Wyczyścić Calculate Values

Disclaimer: This calculator is intended for use with the NIOSH Spirometry Workbook exercises and has NOT been approved by the FDA for clinical use.

A restrictive disease is like a lock on the chest cage or the elastic tissue of the lungs, which limits the expansion of the lung, thus interferes with respiration.

It does not increase and may even decrease the airway resistance, but limits the lung volume from increasing.
Restrictive Pattern

↓ ability of the lungs to expand

- Thoracic cage abnormalities
- Alveolar filling processes
- Pleural disease
- Interstitial diseases

Neuromuscular involvement of the respiratory muscles

- ↓ amount of normally ventilated lung tissue
- ↓ compliance
Pneumonia
Interstitial fibrosis
Restrictive Pattern:

“less air in the lungs”

VC ?
RV ?
FRC ?
TLC ?

Restrictive pattern
Restrictive Pattern
- Always reduced VC
- Always reduced TLC
Obstructive Pattern

Narrowing of lumen of the airways

• ↑ *airway resistance*

• ↓ *flow rate*
Airway resistance:

\[ R = \frac{8\eta l}{\pi r^4} \]

- If \( r \) decreases by the factor of 4, the resistance will increase by a factor 256.

Airflow:

\[ V = \frac{\Delta P}{R} \]
Obstructive Pattern

- ↑ airway resistance
- ↓ rate at which air can move through the lungs

Asthma
Chronic bronchitis
Emphysema
COPD

(Obstruction of lower airways)
Emphysema
Rapid and forced breathing accentuates the airway narrowing!
FORCED (Expiratory) VITAL CAPACITY TEST

determines airway resistance, detects airway obstruction

A VOLUME /TIME CURVE
- A fast rise
- A plateau at the end

Expiration (which follows the maximum inspiration) as forced, fast, and deep as possible
Forced **Expiratory** Vital Capacity Test

A VOLUME /TIME CURVE
A NORMAL VOLUME/TIME CURVE

FVC = 3.89  FEV1 = 3.44

Note: Tracing begins at 0.2 seconds, hence FEV1 is measured at 1.2 seconds.
FORCED (EXPIRATORY) VITAL CAPACITY TEST

Volume - Time Curve

- Spirometry (Volume-time curve)
- Volume (liters)
- Time (seconds)

- FVC
- FEV$_{1,0}$

25% FVC
75% FVC
Line for FEF$_{25-75}$
Parameters **below** the Lower Limits of Normal (LLN) indicate a possible lung disease.

Fixed value for the lower limit of normal

FEV1, (F)V C ≥ 80% of predicted - Normal
- Tiffeneau Ratio - $FEV_1 / VC$

$\geq 0.7 \ (70\%)$

NORMAL

- PseudoTiffeneau Ratio - $FEV_1 / FVC$
Parameters **below** the Lower Limits of Normal (LLN)
indicate a possible lung disease

Fixed value for the lower limit of normal ?

**FEV1, (F)VC ≥ 80% of predicted**

**FEV1/(F)VC ≥ 0.7 (70%)**
A spirogram is a graphic representation of bulk air movement depicted as a volume-time tracing or as a flow-volume tracing.
Forced Vital Capacity Test (FVC)

A. Spirogram

B. Maximal Expiratory Flow - Volume Curve

Maximal Expiratory Flow - Volume Curve (MEFV curve)
Forced (Expiratory) Vital Capacity Test

A Flow/Volume Curve
- A triangle shape with constant decline
FORCED (EXPIRATORY) VITAL CAPACITY TEST

Flow-volume Curve

Flow - Volume Loop

Flow

PEFR

FEF_{25\%}

FEF_{50\%}

FEF_{75\%}

FIF_{50\%}

Volume
(liters)

FVC

0
8
12
4
2
4
6
FVC Test - Obstructive Pattern

- Flow rate?

Normal

Obstruction of lower airways

Flow-volume loop
Obstructive Pattern

FEV1  ?
VC    ?
FVC   ?
FEV1/(F)VC  ?
OBSTRUCTION

VC?

FVC?

Normal

Air trapping - pseudorestriction

Reduced
COPD / EMPHYSEMA

Inspiration

Poor Alveolar Support

Expiration

Excessive Bronchial Collapse

Ruptured Alveolar Wall

Normal Airway

held open by

"Floppy" Airway in

patient with emphy-

sema, no longer

supported by

alveolar tissue

Airway

Alveolar walls

with elastin

fibers

Normal Lung

Emphysematous

Lung

Chestwall (CW)

Lung (L)

pleural space with

negative pressure

"glueing" lung to CW

CW recoil forces

L recoil forces

Figure 160-1. Comparison of normal and emphysematous lung. A normal lung has a well-defined, continuous alveolar wall with tight connections between alveoli. In emphysema, the alveolar walls are thin and the lung has a "floppy" appearance.

Schmidt, Pathology Department, University of Washington
Forced Vital Capacity Test

Obstructive Pattern

FVC [L] 3.11 2.93 94% (Normal)

FEV₁ [L] 2.76 1.67 61% (Reduced)

FEV₁/FVC 0.87 0.57 64% (Reduced)
<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Obs</th>
<th>%Obs/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEV$_1$ [l]</td>
<td>2.28</td>
<td>1.55</td>
<td>68</td>
</tr>
<tr>
<td>FEV1/FVC</td>
<td>0.73</td>
<td>0.57</td>
<td>78</td>
</tr>
<tr>
<td>FVC   [l]</td>
<td>3.11</td>
<td>2.71</td>
<td>87</td>
</tr>
<tr>
<td>PEF   [l/s]</td>
<td>5.78</td>
<td>4.90</td>
<td>85</td>
</tr>
<tr>
<td>FEF$_{25-75}$ [l/s]</td>
<td>2.56</td>
<td>0.59</td>
<td>23</td>
</tr>
</tbody>
</table>
Obstructive pattern

VC ?
RV ?
FRC ?
TLC ?
Obstruction - Other Volumes and Capacities

NORMAL

- Air trapping: ↑RV, ↑FRC, ↓VC
- Hyperinflation: ↑TLC
Figure 172-3. Absolute lung volumes in a normal person, a patient with hyperinflation secondary to obstructive airway disease, and a patient with restrictive lung disease. VC, vital capacity, the volume expired from a maximal inspiration (TLC, total lung capacity) to full expiration (RV, residual volume); FRC, functional residual capacity, volume at end of a normal tidal breath; IC, inspiratory capacity; TV, tidal volume; ERV, expiratory reserve volume.

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Obstruction-hyperinflated</th>
<th>Restriction</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC (liters)</td>
<td>6.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>TLC (liters)</td>
<td>8.0</td>
<td>10.0</td>
<td>5.0</td>
</tr>
<tr>
<td>FRC (liters)</td>
<td>4.0</td>
<td>7.0</td>
<td>3.0</td>
</tr>
<tr>
<td>RV (liters)</td>
<td>2.0</td>
<td>6.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>
FVC Test - Obstruction

- $\text{FEV}_1 \ [\text{L}]$ - Reduced
- $\text{F}(\text{VC}) \ [\text{L}]$ - Normal or reduced

- $\text{FEV}_1$ to (F)VC ratio – Reduced !!!
Maximum expiratory and inspiratory flow volume curves with examples of how respiratory disease can alter its shape:

a) normal subject

b) obstructive airway disease (e.g. asthma)

c) severe obstructive disease (e.g. emphysema)

d) restrictive lung disease (e.g. pulmonary fibrosis)

e) fixed major airway obstruction (e.g. carcinoma of the trachea).
Typical Flow-Volume Curves

Normal Curves

Risk  Obstruction  Restriction  Tracheal stenosis
Obstruction Of Upper Airway, Trachea, Large Bronchi - less common, can be suggested by spirometry

**Variable**

(airflow is compromised by dynamic changes in airway diameter)

<table>
<thead>
<tr>
<th>Intrathoracic</th>
<th>Extrathoracic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracheomalacia</td>
<td>Vocal cords paralysis,</td>
</tr>
<tr>
<td>Neoplasm</td>
<td>Thyromegaly Tracheomalacia</td>
</tr>
<tr>
<td></td>
<td>Neoplasm</td>
</tr>
</tbody>
</table>

**Flat expiration**

**Flat inspiration**
Obstruction Of Upper Airway, Trachea, Large Bronchi - less common, can be suggested by spirometry

**Fixed**

<table>
<thead>
<tr>
<th>Intrathoracic</th>
<th>Extrathoracic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracheal stenosis</td>
<td>Foreign body Neoplasm</td>
</tr>
</tbody>
</table>

Flow/Volume Curve is flat for inspiration and expiration (a squared loop)

A specific, but not sensitive sign
Fixed Upper Airway Obstruction
FORCED VITAL CAPACITY TEST

Restrictive Pattern

„Less air in the lungs‟

FVC ?

FEV₁ ?

FEV₁ to FVC ratio ?
FVC Test – Restriction

- FEV$_1$ [L] - Reduced
- F(VC) [L] - Reduced

FEV$_1$ reduced less than F(VC)

FEV$_1$ to (F)VC ratio - NORMAL or INCREASED
Flow - volume curve:

- shape - relatively unaffected
- overall size - appears ↓ when compared to normal on the same curve

<table>
<thead>
<tr>
<th>N</th>
<th>Obs</th>
<th>%Obs/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEV$_1$ [l]</td>
<td>1.90</td>
<td>0.94</td>
</tr>
<tr>
<td>FEV1/FVC</td>
<td>0.7</td>
<td>0.98</td>
</tr>
<tr>
<td>FVC [l]</td>
<td>2.75</td>
<td>0.96</td>
</tr>
<tr>
<td>PEF [l/s]</td>
<td>5.40</td>
<td>2.98</td>
</tr>
<tr>
<td>FEF$_{25-75}$ [l/s]</td>
<td>2.11</td>
<td>2.25</td>
</tr>
</tbody>
</table>
Obstructive changes with reduced VC (additional concurrent restriction?)
MEASUREMENT OF TLC

- impossible by a direct method /spirometry/ !

MEASUREMENT OF RV (FRC, TLC) -

INDIRECT !

(Closed-Circuit Helium Method)
The Closed - Circuit Helium Method

Method - rebreathing from the closed circuit to the point of stabilization of helium concentration.

Start of the test - at the end of quiet expiration

The total amount of helium does not change

\[ F_1 \times V_1 = F_2 \times (V_1 + FRC) \]

- \( V_1 \) – initial volume of the system (apparatus)
- \( F_1 \) – initial concentration of helium
- \( F_2 \) – final concentration of helium
- \( V_1 + FRC \) – final volume of the system (apparatus + FRC)
Figure 19-4  The closed-circuit He apparatus for the determination of functional residual capacity. The system is essentially a spirometer with accessories that enable addition of $O_2$ and He, removal of $CO_2$, mixing of the gases and analysis of He concentration.
The Closed - Circuit Helium Method

• Helium is insoluble and not taken up by blood

• The subject is connected with the spirometer filled with 10% helium in air.

• Method - rebreathing from the closed circuit to the point of stabilization of helium concentration - **The total amount of helium does not change**

(The helium concentration in the lungs becomes the same as in the spirometer after the subject rebreathes the helium-air mixture).

If the test starts at the end of normal expiration – the amount of air remaining in the lungs represents FRC

If the test starts at the end of deepest expiration – the amount of air remaining in the lungs represents RV

\[
F1 \times V1 = F2 \times (V1+FRC)
\]

\[
FRC = \frac{V1 (F1-F2)}{F2}
\]

V1 – initial volume of the system (apparatus)
F1 – initial 10% concentration of helium in the apparatus
F2 – final concentration of helium (after equilibration)
V1+FRC – final volume of the system (apparatus + FRC)
2. The Nitrogen Washout Method

Apparatus: open - circuit

Method: collection of air expired during breathing 100% O₂ (7\')
Start of the test - at the end of quiet expiration

Parameters known or measured:
- Concentration of nitrogen in the lungs
- Concentration of nitrogen in expired gas
- Volume of expired gas,

Parameter unknown:
- Volume of gas in the lungs = FRC

The total amount of nitrogen in the lung at the beginning of the test equals the amount of nitrogen collected in the bag.

Concentration of nitrogen in the lungs \( \times \) Volume of gas in the lungs = Concentration of nitrogen in expired gas \( \times \) Volume of expired gas
The following spirogram was obtained from a 23-year-old woman, who was asked to inspire maximally (A to B) and then to expire maximally (from B to C).

1. The forced vital capacity (FVC) is
   A. 500 ml  
   B. 2000 ml  
   C. 4000 ml  
   D. 5500 ml  
   E. Cannot be determined

2. The forced expiratory volume (FEV₁) in 1 second is
   A. 500 ml  
   B. 2200 ml  
   C. 3000 ml  
   D. 5500 ml  
   E. Cannot be determined

3. The residual volume (RV) is
   A. 1000 ml  
   B. 1500 ml  
   C. 1200 ml  
   D. One half the functional residual capacity  
   E. Cannot be determined
The following spirogram was obtained from a 23-year-old woman, who was asked to inspire maximally (A to B) and then to expire maximally (from B to C).

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   D. 5500 ml
   E. Cannot be determined

3. The residual volume (RV) is
   A. 1000 ml
   B. 1500 ml
   C. 1200 ml
   D. One half the functional residual capacity
   E. Cannot be determined
The spirogram of the forced vital capacity (FVC) was obtained from a male patient weighting 70 kg.

4. The forced expiratory volume in 1 second (FEV₁) to FVC ratio is
   A. 50%
   B. 75%
   C. 80%
   D. 100%
   E. Not able to be determined

5. The FEV₁ to FVC ratio is typical of
   A. healthy individuals
   B. a restrictive pattern of pulmonary disease
   C. an obstructive pattern of pulmonary disease
   D. patients with interstitial pulmonary fibrosis
   E. pulmonary edema

6. Which of the following statements about this patient is true?
   A. Had the FRC been measured, it would have been less than predicted
   B. Had the TLC been measured, it would have been less than predicted
   C. Had the RV been measured, it would have been less than predicted
   D. The expiratory flow rate (liters/s) is greater than predicted
   E. None of them
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B. Had the TLC been measured, it would have been less than predicted
C. Had the RV been measured, it would have been less than predicted
D. The expiratory flow rate (liters/s) is greater than predicted
E. None of them
7. Which one of the following would increase in obstructive, but not in restrictive, lung disease?
A. \( \text{FEV}_1 \)
B. \( \text{FEV}_1 / \text{FVC} \)
C. Vital capacity
D. Functional residual capacity
E. Breathing frequency

8. Which of the following conditions is most likely to produce the change from the normal maximum flow-volume curve illustrated below?
A. Asthma
B. Emphysema
C. Bronchiolitis
D. Fibrosis
E. Fatigue

9. Which one of the followings will be closest to normal in a patient with restrictive lung disease?
A. \( \text{RV} \)
B. \( \text{VC} \)
C. \( \text{FVC} \)
D. \( \text{FEV}_1 / \text{FVC} \)
E. \( \text{TLC} \)
7. Which one of the following would increase in obstructive, but not in restrictive, lung disease?
A. FEV₁
B. FEV₁/FVC [%]
C. Vital capacity
D. Functional residual capacity
E. Breathing frequency

8. Which of the following conditions is most likely to produce the change from the normal maximum flow-volume curve illustrated below?
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B. Emphysema
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D. Fibrosis
E. Fatigue

9. Which one of the followings will be closest to normal in a patient with restrictive lung disease?
A. RV
B. VC
C. FVC
D. FEV₁/FVC
E. TLC
Questions 10-12. The information which follows was obtained from a 23-year-old patient during a complete work-up (direct spirometry; closed circuit helium method) in a pulmonary function laboratory:

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total lung capacity</td>
<td>7.0 L</td>
</tr>
<tr>
<td>Inspiratory capacity</td>
<td>4.0 L</td>
</tr>
<tr>
<td>Inspiratory reserve volume</td>
<td>3.5 L</td>
</tr>
<tr>
<td>Expiratory reserve volume</td>
<td>1.5 L</td>
</tr>
</tbody>
</table>

10. The tidal volume (TV) is
A. 100 ml
B. 350 ml
C. 500 ml
D. 1000 ml
E. cannot be determined given the above data

11. The vital capacity (VC) is
A. 3.0 L
B. 5.0 L
C. 5.5 L
D. 6.0 L
E. 7.0 L

12. The functional residual capacity (FRC) is
A. 0.5 L
B. 3.0 L
C. 3.5 L
D. 4.0 L
E. not measurable given the above data
**Questions 10-12.** The information which follows was obtained from a 23-year-old patient during a complete work-up (direct spirometry; closed circuit helium method) in a pulmonary function laboratory:

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<td>Inspiratory reserve volume</td>
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<td>Expiratory reserve volume</td>
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C. 5.5 L  
D. 6.0 L  
E. 7.0 L  

12. The functional residual capacity (FRC) is
A. 0.5 L  
B. 3.0 L  
C. 3.5 L  
D. 4.0 L  
E. not measurable given the above data
Thank you
Compliance of the Lungs (an index of lung distensibility)

\[ C_L = \frac{\Delta V}{\Delta P} \] (200 - 230 ml/ 1 cm H\(_2\)O)

- a slope of pressure - volume curve
Figure 20–18
Lung pressure-volume curve and compliance. A lung with a slope greater than normal would have an abnormally high compliance. A lung with a slope smaller than normal would have an abnormally low compliance.
Figure 163–1. Severe pulmonary fibrosis. The majority of the lung tissue is consolidated because of a combination of air space collapse and accumulations of nondistensible fibrous tissue within the interstitium and former air spaces. Little functional gas-exchange tissue is present except for a few partially collapsed alveoli. Compare with normal lung in Figure 160–1A. Original magnification = 75×. (Courtesy of Dr. Rodney Schmidt, Pathology Department, University of Washington)
↓ compliance:

- Pulmonary congestion
- Interstitial pulmonary fibrosis
- Alveolar filling processes (pneumonia, alveolar edema)
- Respiratory distress syndrome
Figure 20–18
Lung pressure-volume curve and compliance. A lung with a slope greater than normal would have an abnormally high compliance. A lung with a slope smaller than normal would have an abnormally low compliance.
↑ compliance:
- emphysema
- age