A Stepwise Approach to the Interpretation of Pulmonary Function Tests

Zaza Cohen, MD, FCCP

Financial Disclosures

- None

PFT – Why Order Them?

- To identify and quantify changes in pulmonary function
  - Gives a pattern of disease, not a diagnosis
- Assess need for or effectiveness of therapy
  - Decide on treatment, evaluate progression or response to therapy
- Screen for pulmonary involvement
- Preoperative evaluation for complications
  - Rarely performed unless a major thoracic surgery or lung resection surgery is planned
- Disability evaluation

PFT – When NOT To Order

- Unstable patient
- Chest or abdominal pain
- Recent surgery (including eye surgery)
- Nausea/Vomiting
- Acutely/critically ill
- Unable to follow detailed commands
  - Valid and reliable results cannot be expected

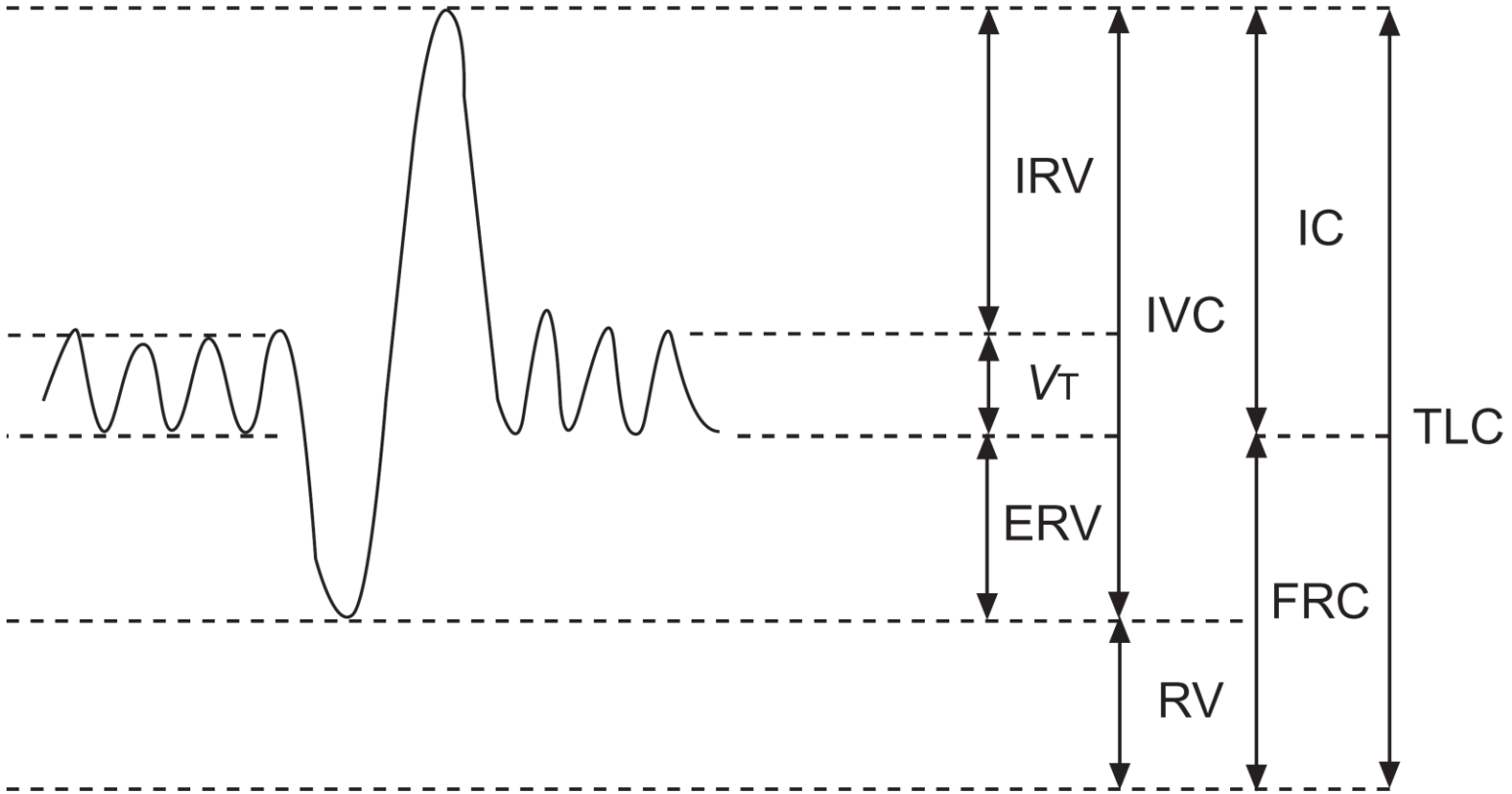
PFT – What Do (Can) I Get?

- Conventional PFT
  - Spirometry, lung volumes, DLCO
- Additional tests
  - Bronchodilator challenge
  - Methacholine challenge
  - Mip, Mep, etc
- Cardiopulmonary Exercise Testing (CPET)
  - Exercise oxymetry
  - 6 minute walk test
- Arterial Blood Gases (ABG)

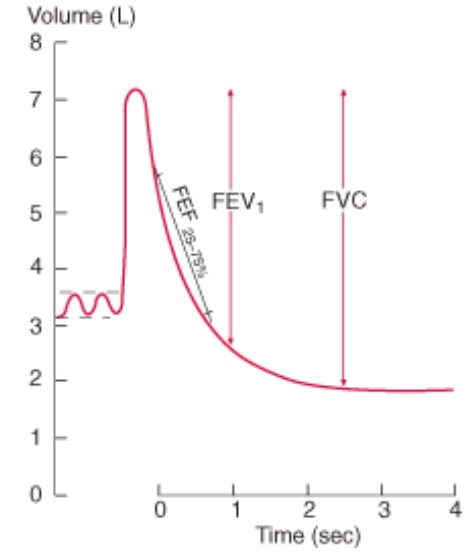
PFT – What Shall I Read?

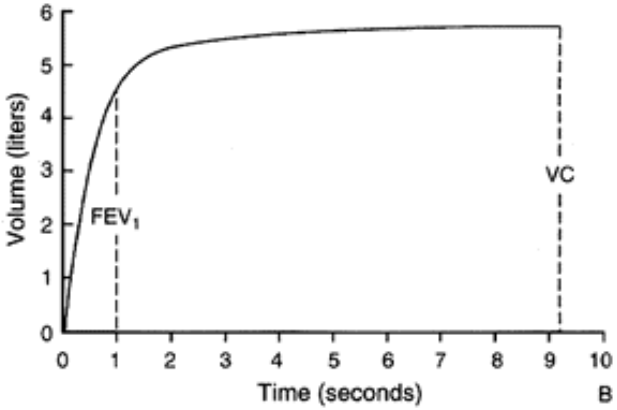
- Reliability of data (GIGO)
- Normal vs. Abnormal
- Pattern of the abnormality
- Severity of the disease
- Clues to clinical diagnosis
  - "clinical correlation is suggested"

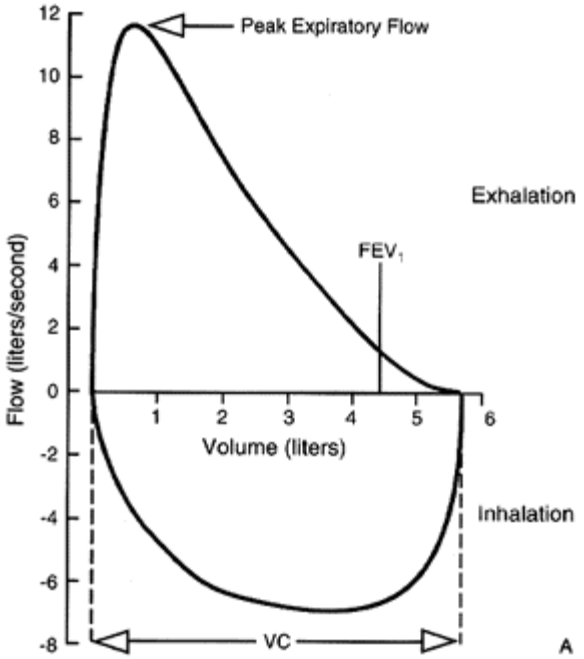
Physiology & Definitions



PFT – Making Sense of The Graphs







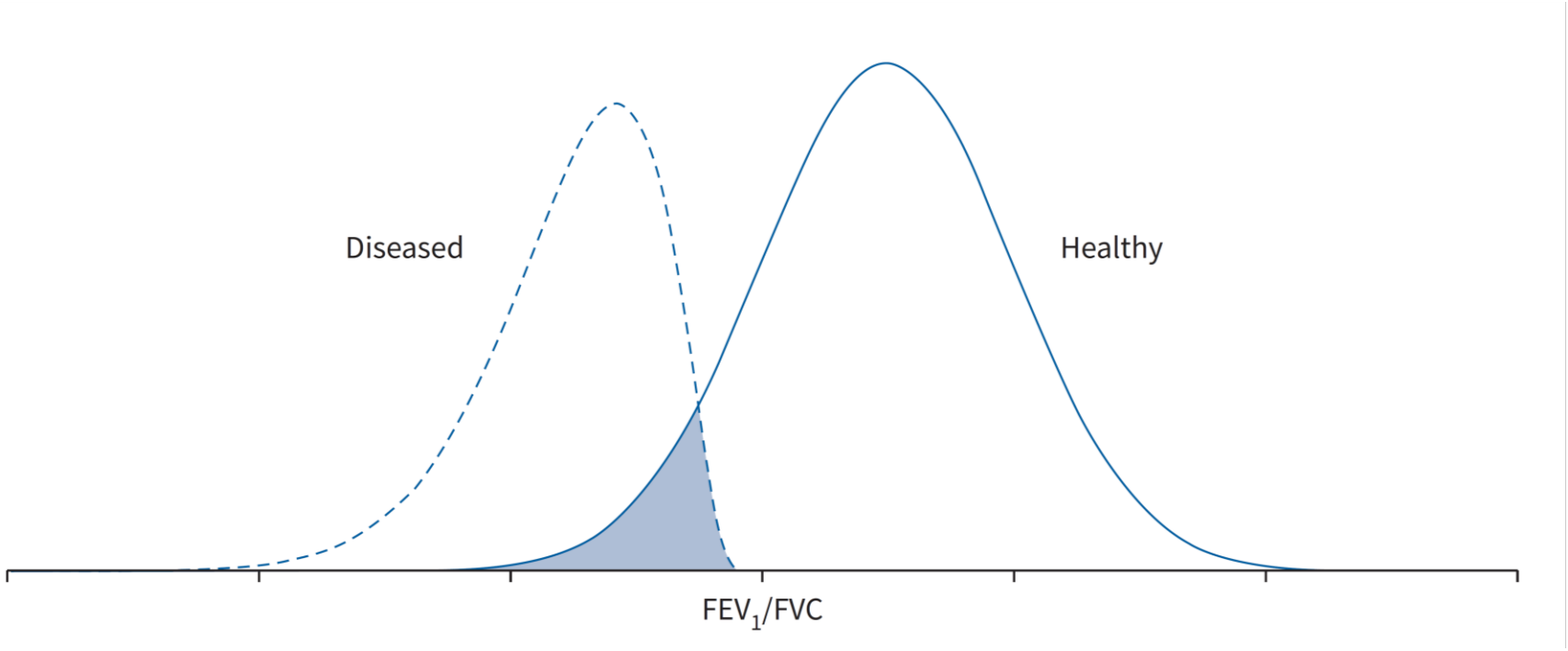
Troubleshooting

- Good expiratory plateau
- Expiration lasted at least 6 seconds
- Back extrapolation adequate
- No cough interference
- Up to eight spirometry maneuvers done
- Best FEV1 and FVC are reported, even if they come from separate maneuvers
- Technician must evaluate report poor patient effort

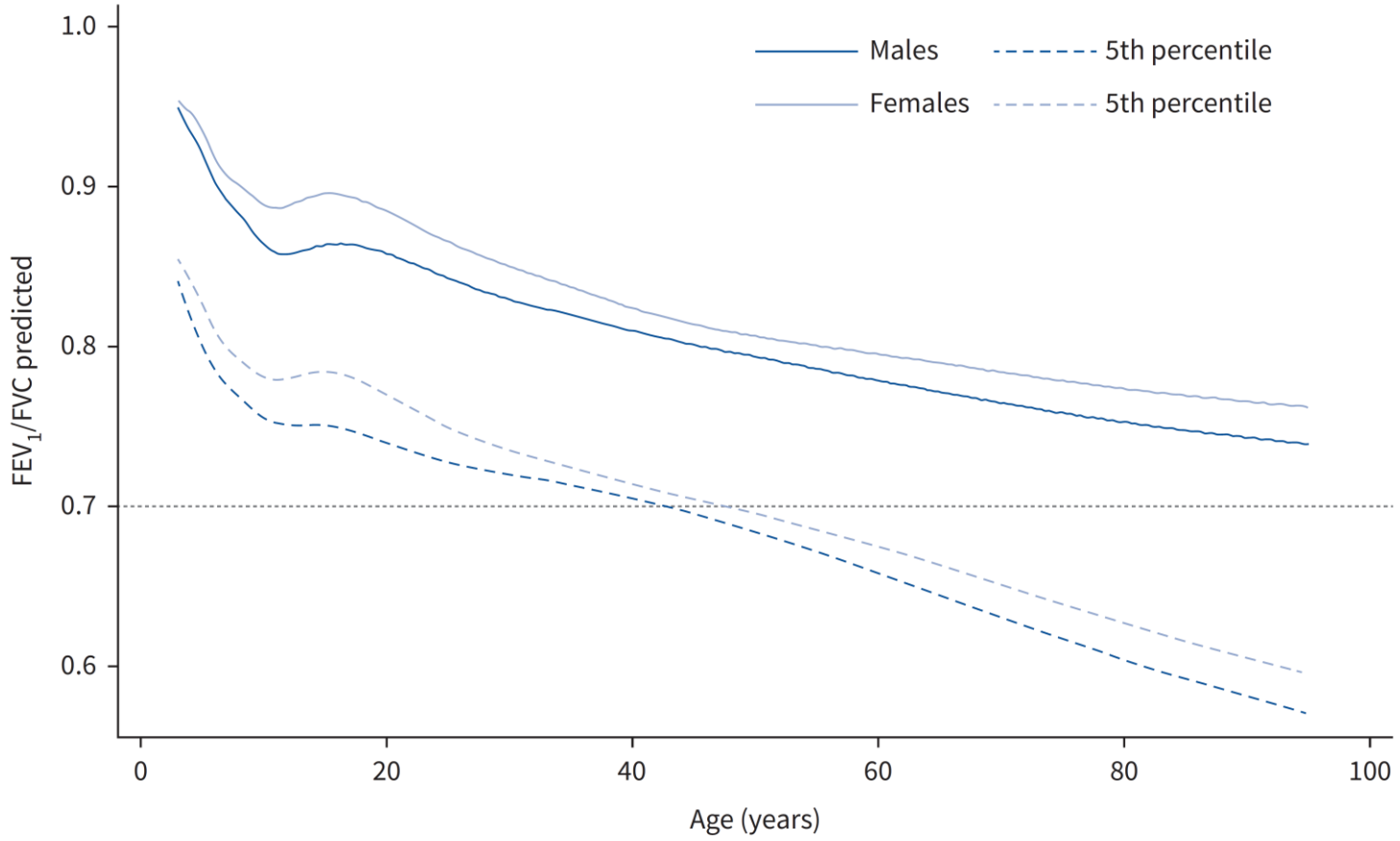
Reference Values

- Normal PFT values depend on:
  - Height
  - Age
  - Gender (biological)
  - Race/Ethnicity
- Reference values and formulas to derive it are based on large population-based studies
- “Normally abnormal” vs. “abnormally normal”

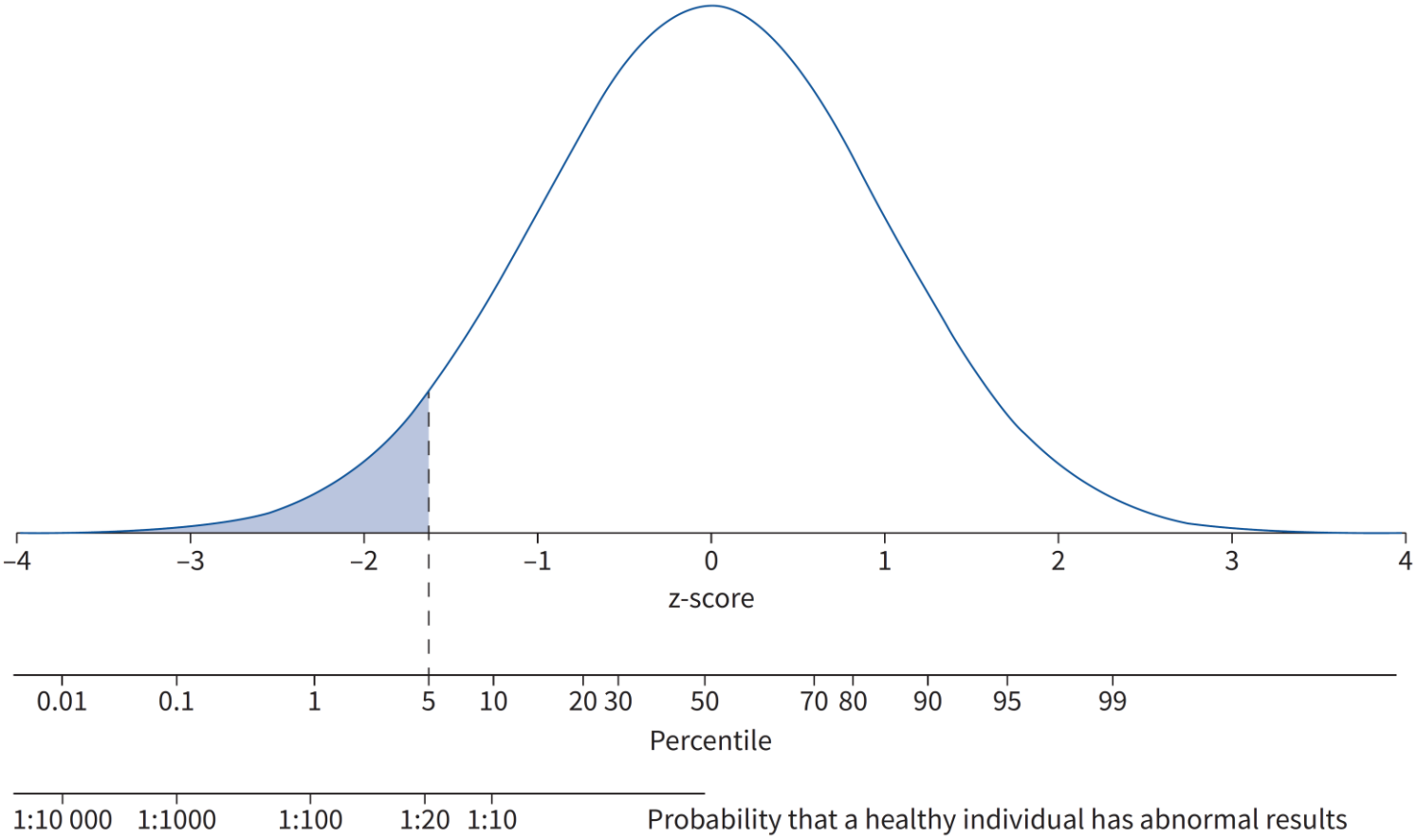
Health vs. Disease



FEV1/FVC – What's Abnormal?



ULN, LLN and z-Scores



Let's Agree to Disagree

TABLE 3 The 5th percentile values (lower limit of normal (LLN)) for various lung function indices expressed as percent predicted for six individuals

	Male (age 10 years; height 137 cm)	Female (age 15 years; height 162 cm)	Male (age 25 years; height 175 cm)	Female (age 25 years; height 165 cm)	Male (age 80 years; height 175 cm)	Female (age 80 years; height 165 cm)
FEV_1	81.3	80.5	80.5	80.2	69.4	70.0
FVC	81.2	80.4	80.9	79.9	72.0	70.0
FEV_1/FVC	87.4	87.8	86.9	87.2	80.0	80.5
TLC	78.0	79.8	80.0	80.4	77.8	77.6
FRC	70.9	69.9	69.6	72.5	69.8	70.7
RV	40.6	40.9	49.1	52.5	55.7	57.7
D_{LCO}	75.4	77.5	79.0	77.8	72.4	74.5

FEV_1: forced expiratory volume in 1 s; FVC: forced vital capacity; TLC: total lung capacity; FRC: functional residual capacity; RV: residual volume; D_{LCO}: diffusing capacity of the lung for carbon monoxide. Global Lung Function Initiative reference equations were used for all indices [10–12]. The table demonstrates that the equivalent percent predicted value at the LLN varies considerably for individuals of different ages and for each pulmonary function index, and highlights the potential bias introduced when using percent predicted thresholds for defining normal limits.

PFT

- Basic Evaluation:
  - FEV1
  - VC (usually FVC)
  - FEV1/VC
  - TLC
  - RV/TLC
  - ERV
  - DLCO
  - Flow-volume loop (FVL)
- Additional Test:
  - Bronchoprovocation test
  - Bronchodilator response
  - FEF 25-75%
  - MIP, MEP
  - Pseudorestriction
  - Pseudo-pseudorestriction

Patterns of Disease

- Normal
- Obstructive
  - FEV1/VC is low
  - FVC is normal or low
- Restrictive
  - FEV1/VC is normal
  - FVC is low
- Mixed
  - FEV1/VC is low
  - FVC is usually low

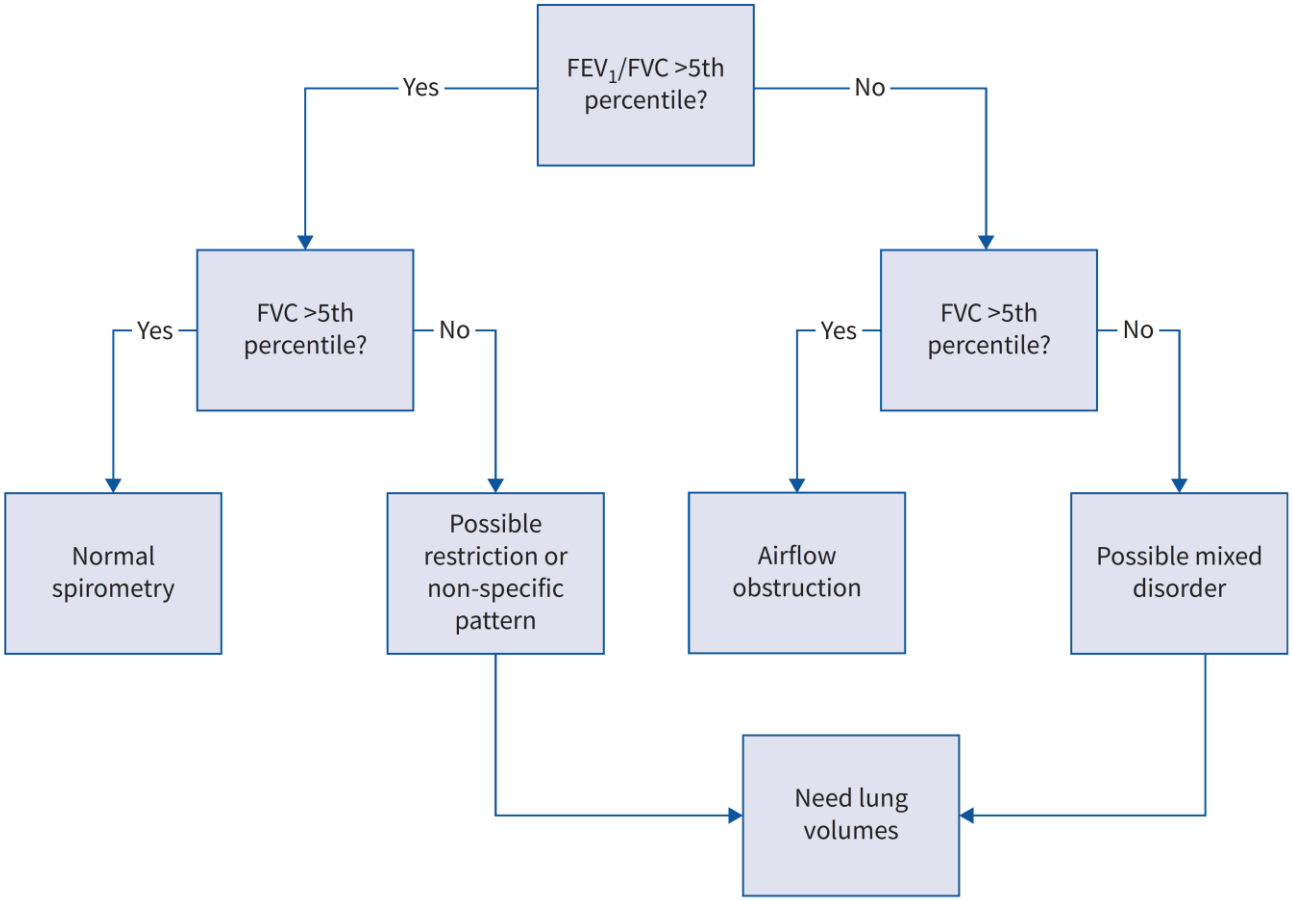
Spirometry Interpretation

TABLE 5 Classification of ventilatory impairments defined by spirometry (reduced or elevated results are defined by the lower and upper limits of normal, respectively)

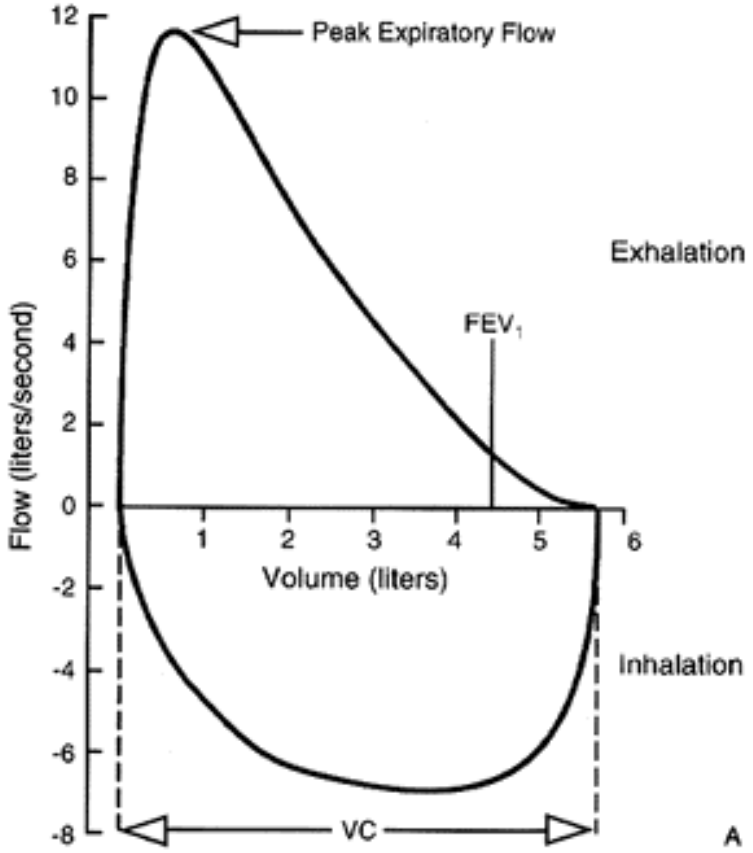
	FEV_1	FVC	FEV_1/FVC	Comments
Obstructive impairments	Normal/↓	Normal	↓	
Restrictive impairments	↓	↓	Normal/↑	TLC reduced to confirm
Non-specific pattern [121]	↓	↓	Normal	TLC normal (additional testing may be helpful, *e.g.* bronchodilator response, R_{aw}); when TLC is not available, this pattern has been described in population-based studies as preserved ratio impaired spirometry (PRISm) in current and former smokers [122]
Muscle weakness	↓	↓	Normal	Lack of sharp PEF
Suboptimal effort	↓	↓	Normal	Lack of sharp PEF
Mixed disorder	↓	↓	↓	Need lung volumes to confirm
Dysanapsis [118]	Normal	Normal/↑	↓	May be normal variant

FEV_1: forced expiratory volume in 1 s; FVC: forced vital capacity; TLC: total lung capacity; R_{aw}: airway resistance; PEF: peak expiratory flow.

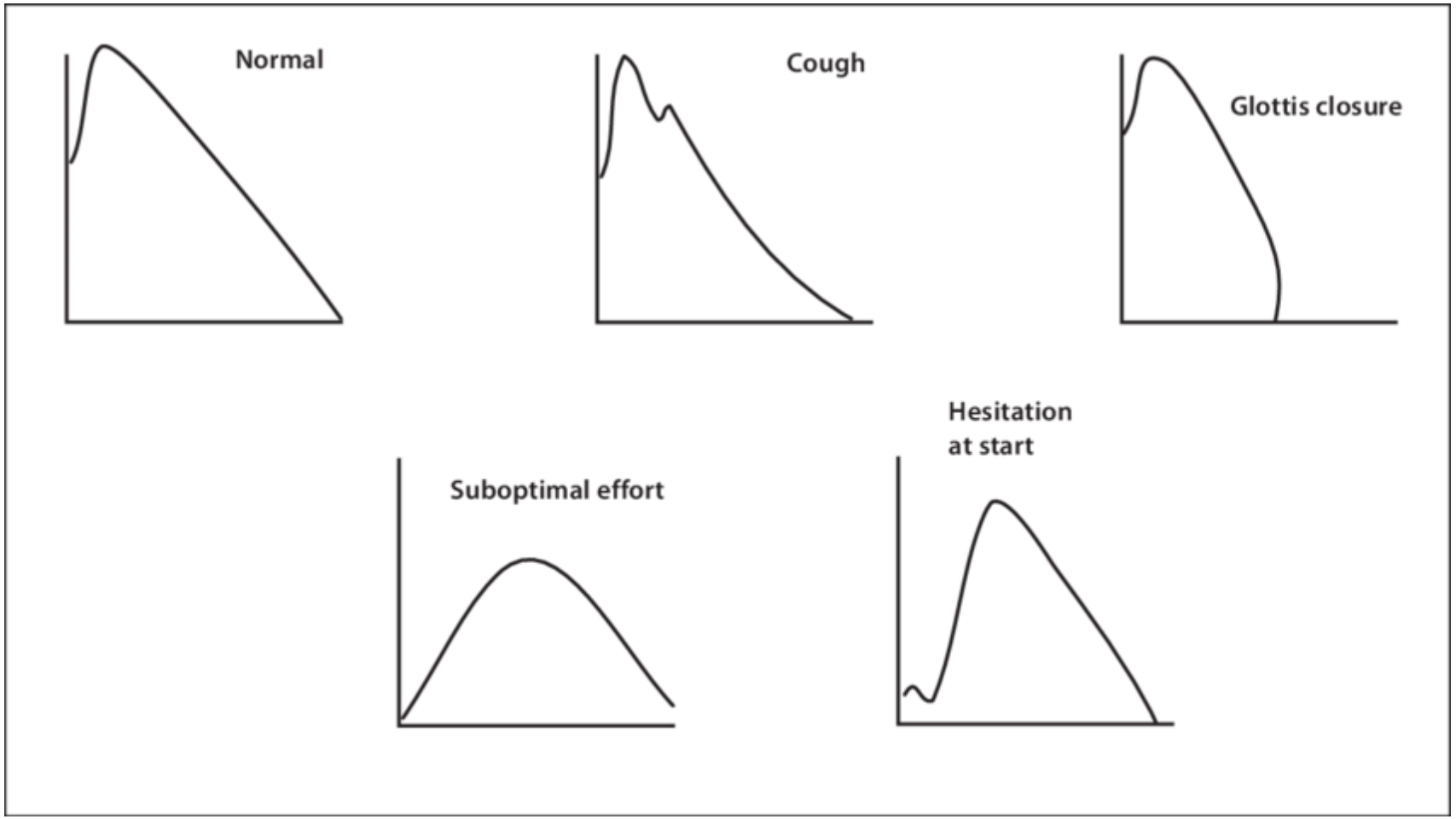
Spirometry Interpretation



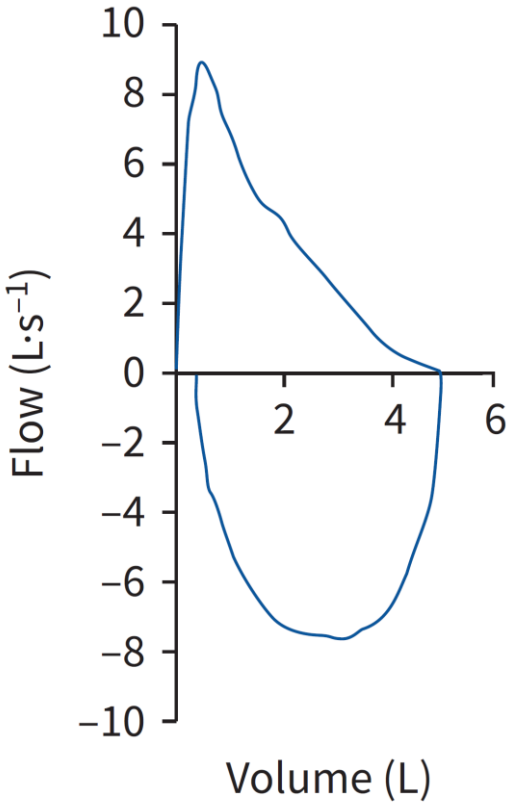
Flow Volume Loop



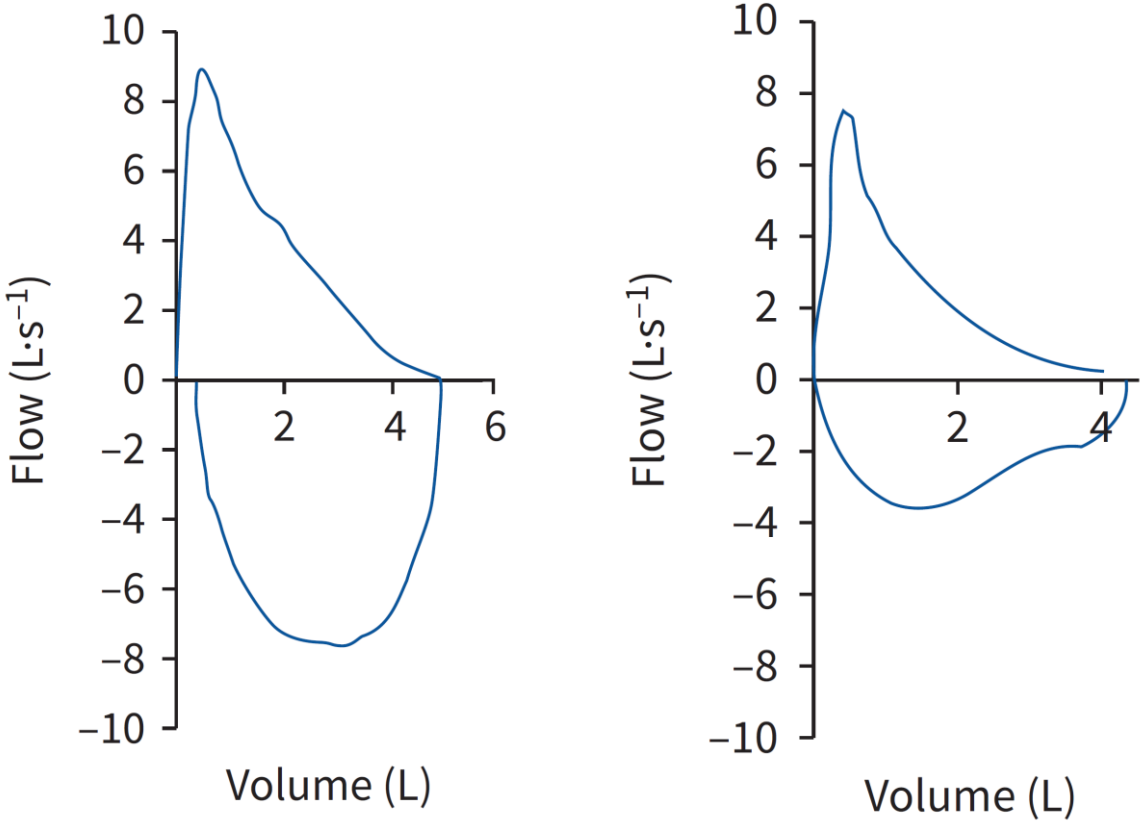
FVL – Patters of Poor Quality Test

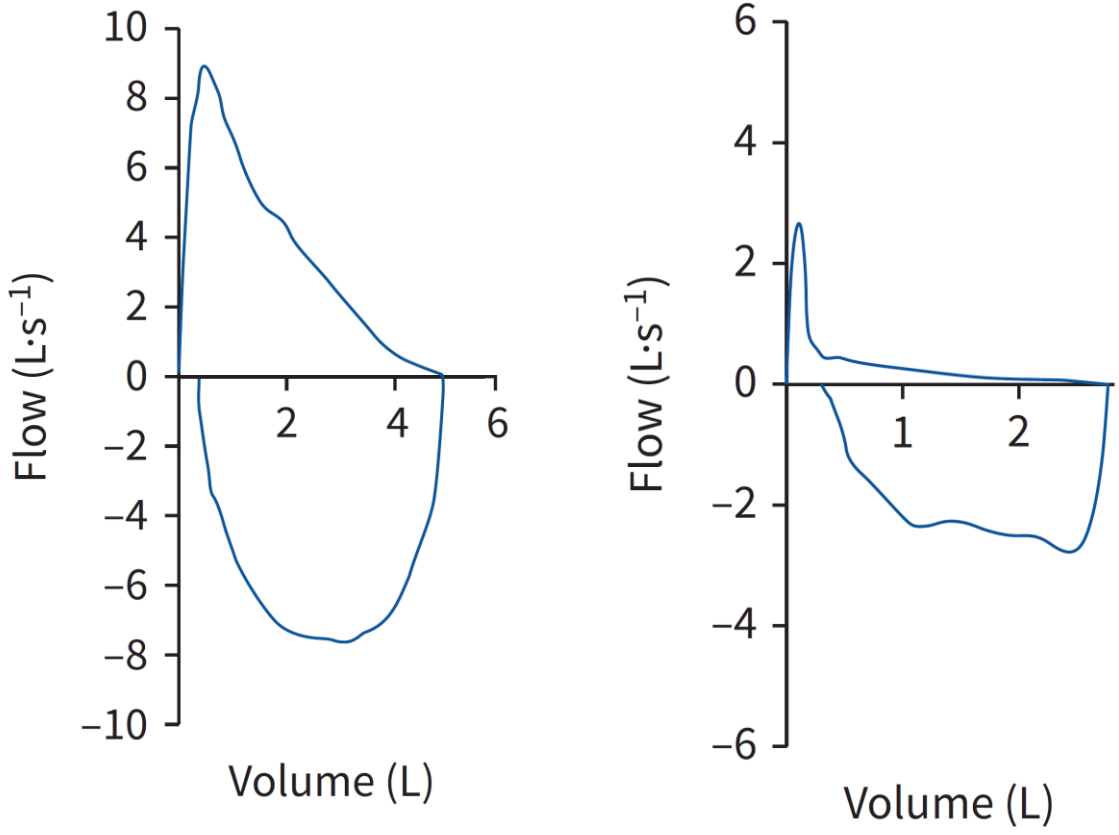


Interpreting FVL

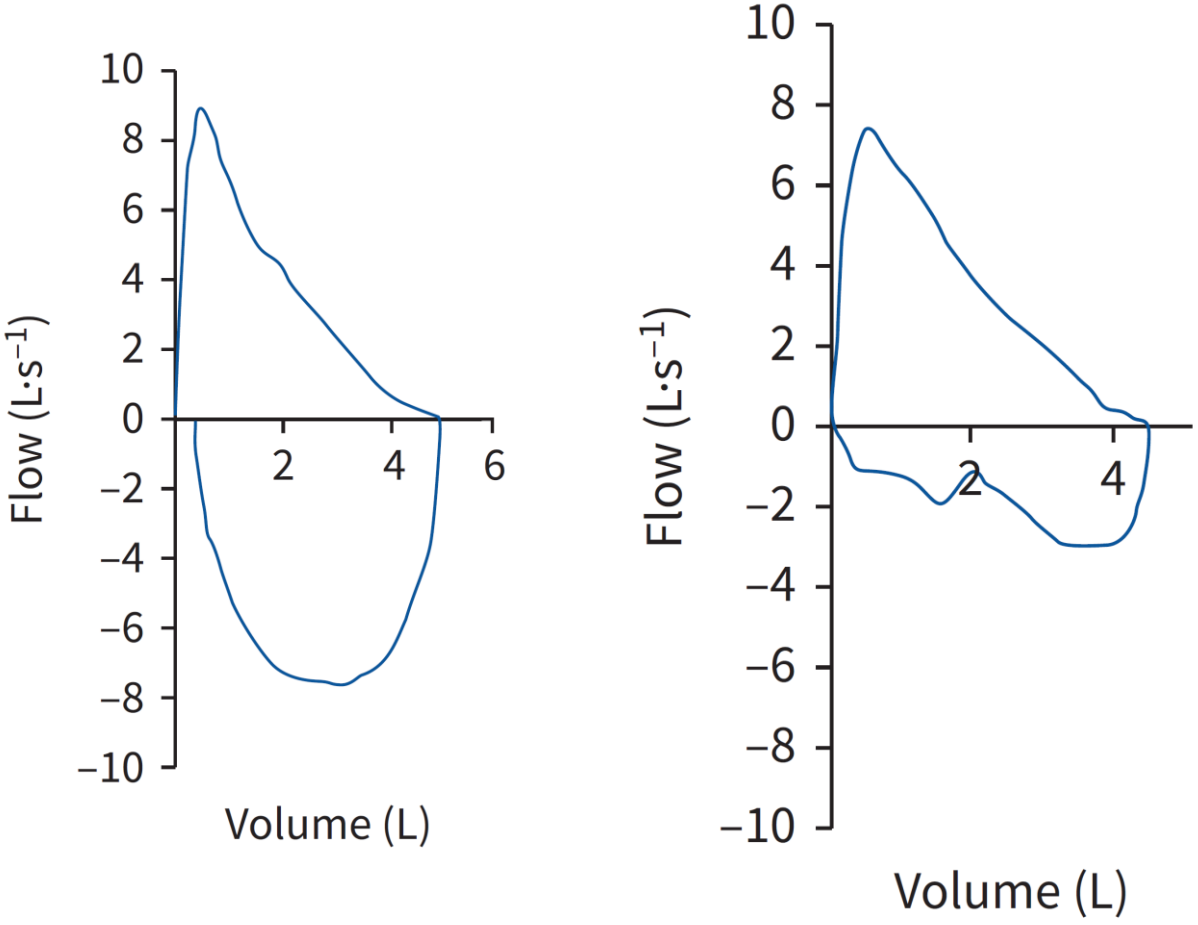


Interpreting FVL

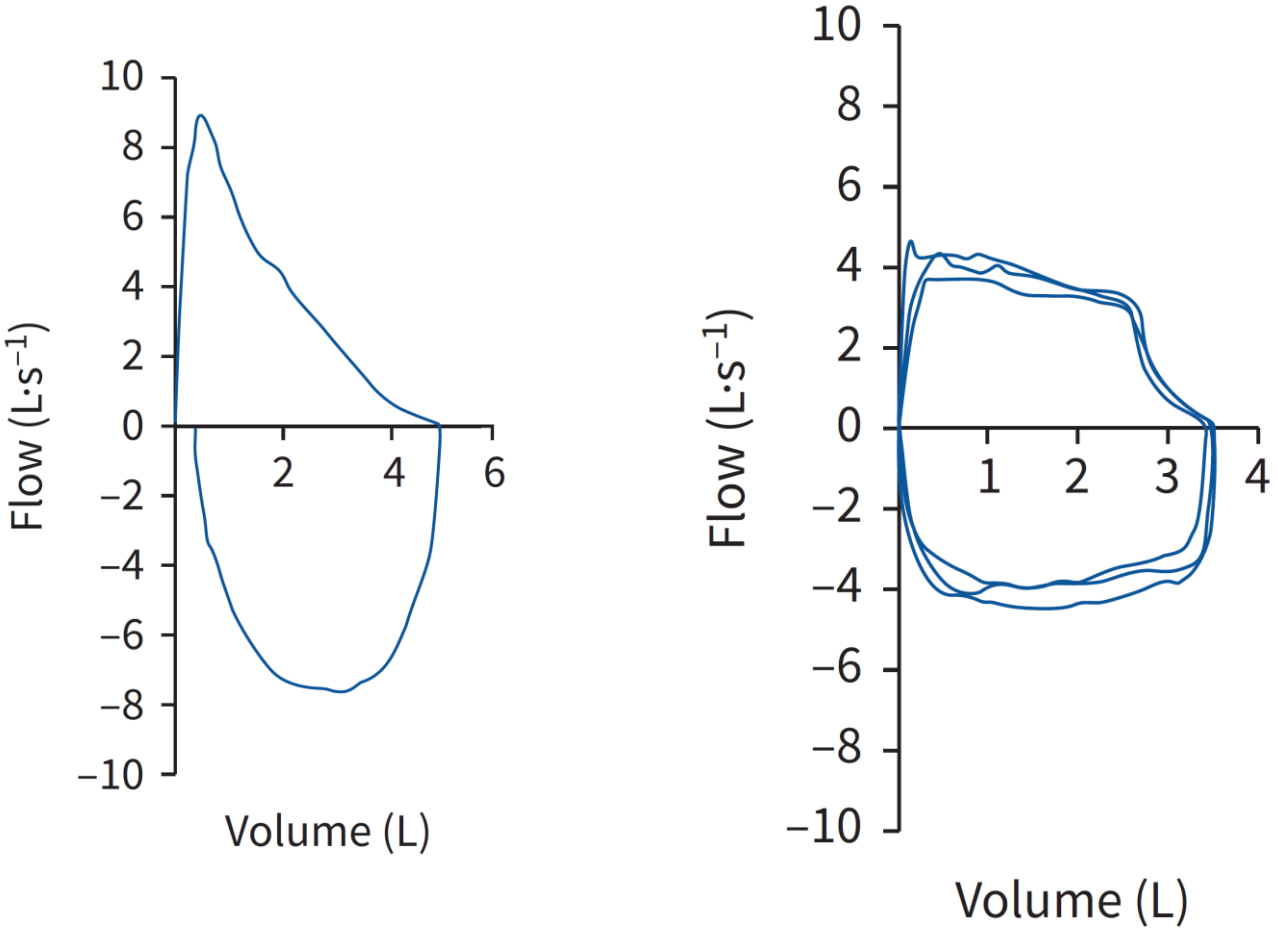



10
8
6
4
2
0
−2
−4
−6
−8
−10
2
4
6
Flow (L·s−1)
Volume (L)
6
4
2
0
−2
−4
−6
1
2
Flow (L·s−1)
Volume (L)

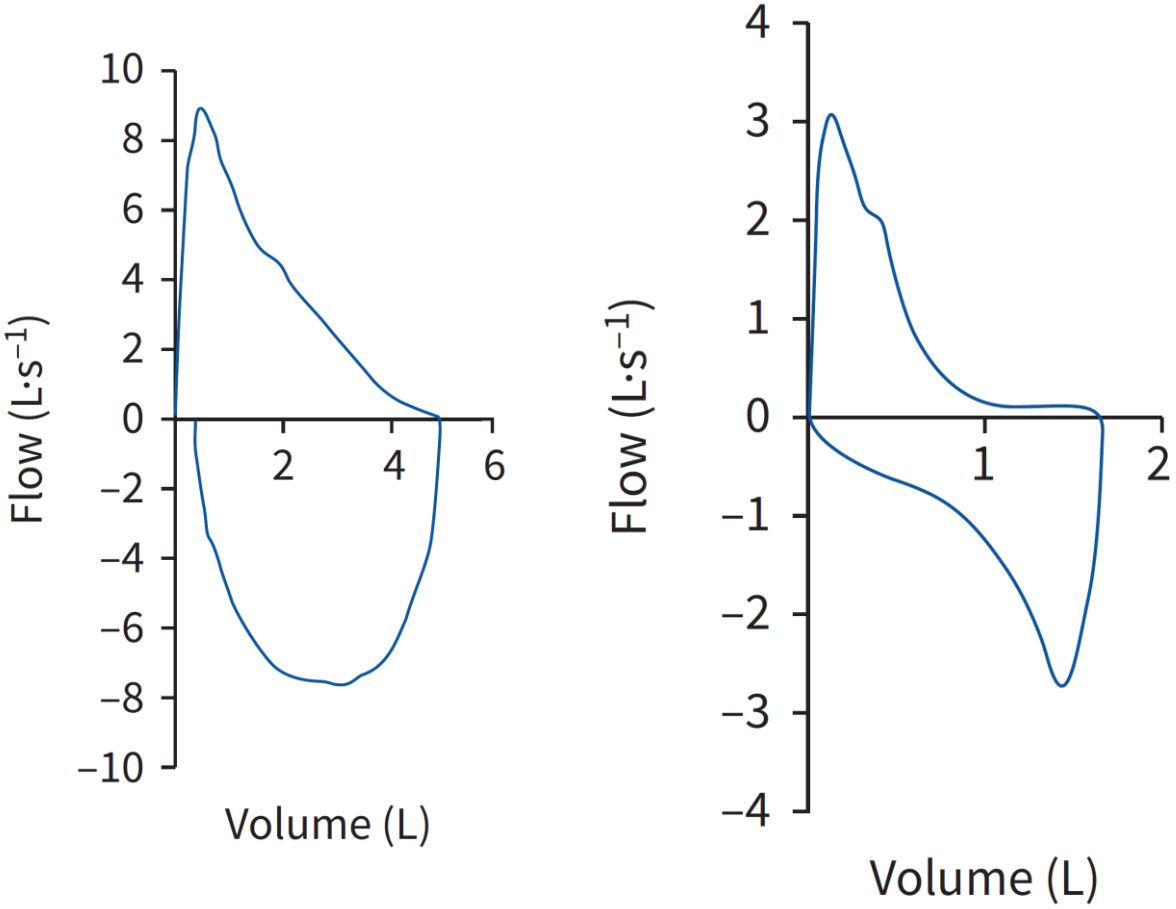
Interpreting FVL



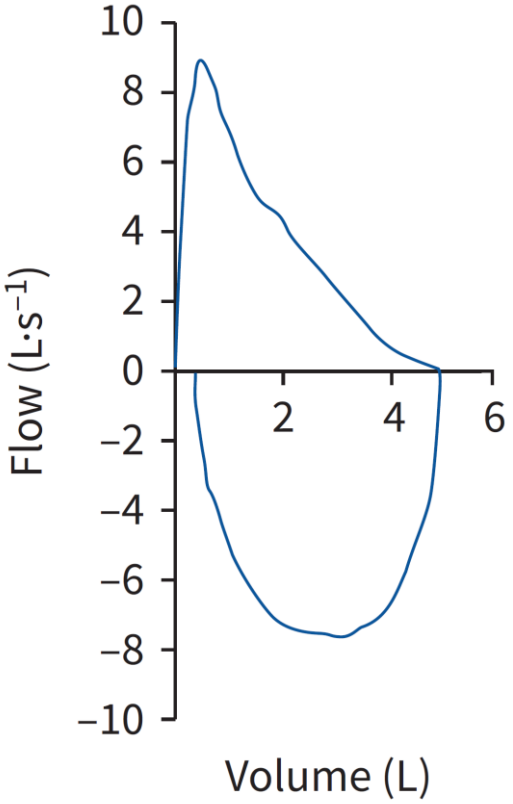
Interpreting FVL

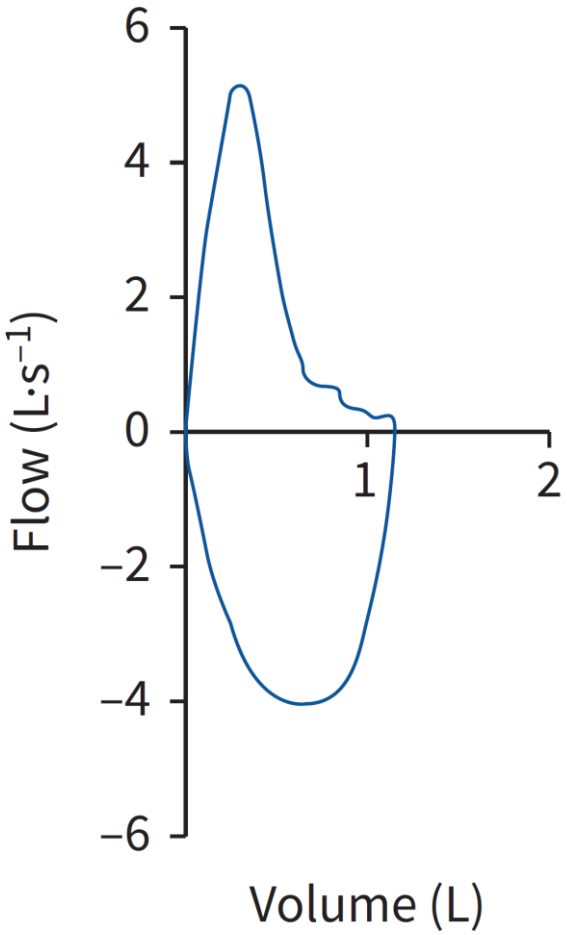


Interpreting FVL

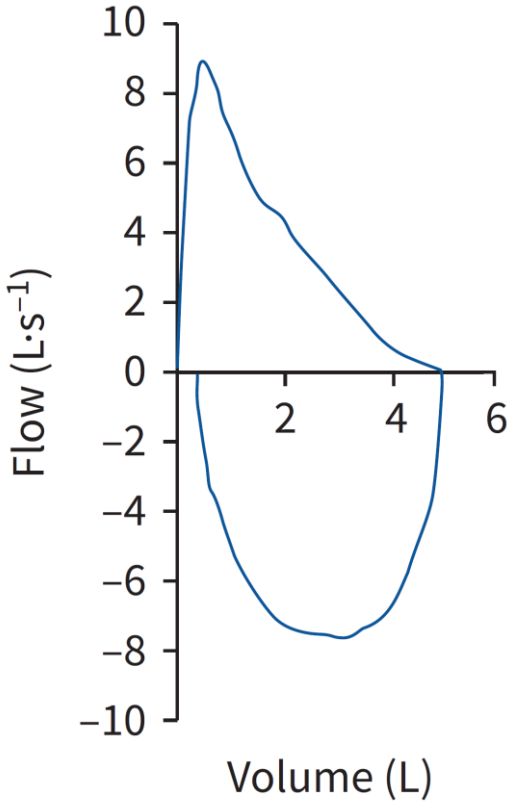


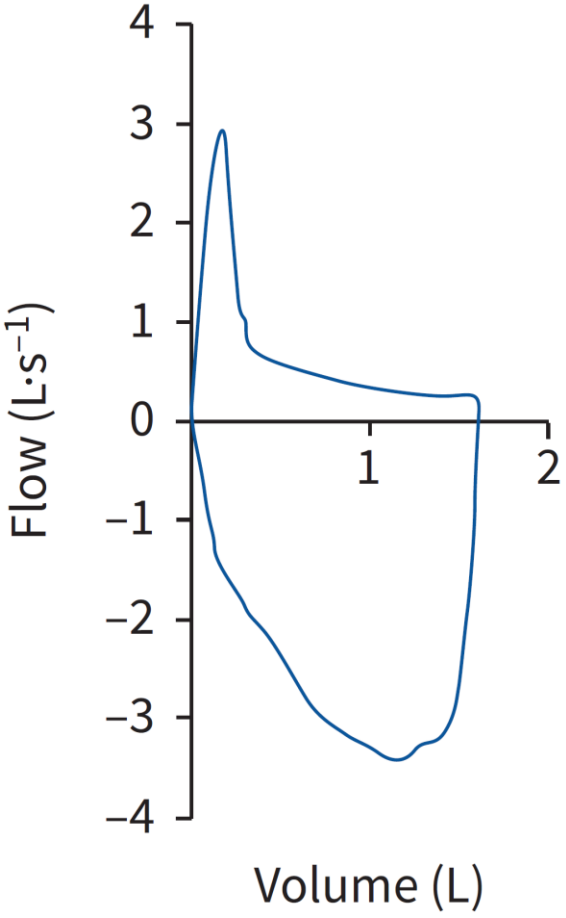
Interpreting FVL





Interpreting FVL





Lung Volumes – Tale of Two Tests

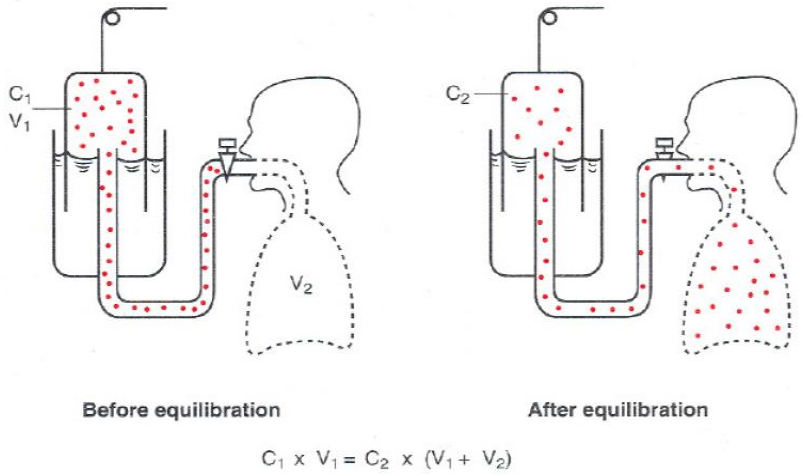
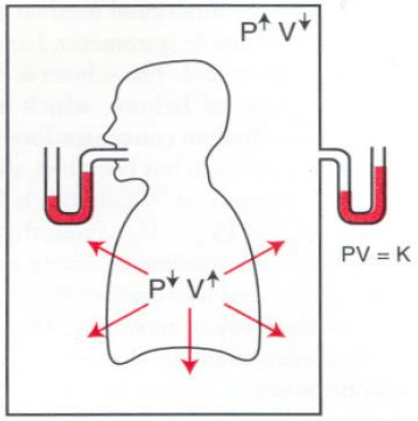


Figure 2-3. Measurement of the functional residual capacity by helium dilution.

- Helium Dilution
  - Inaccurate
  - May miss air trapping
  - Widely available

Figure 2-4. Measurement of functional residual capacity (FRC) with a body plethysmograph. When the subject makes an inspiratory effort against a closed airway, he slightly increases the volume of his lung, airway pressure decreases, and box pressure increases. From Boyle's law, lung volume is obtained (see text).



- Plethysmography
  - More accurate
  - Not routinely available

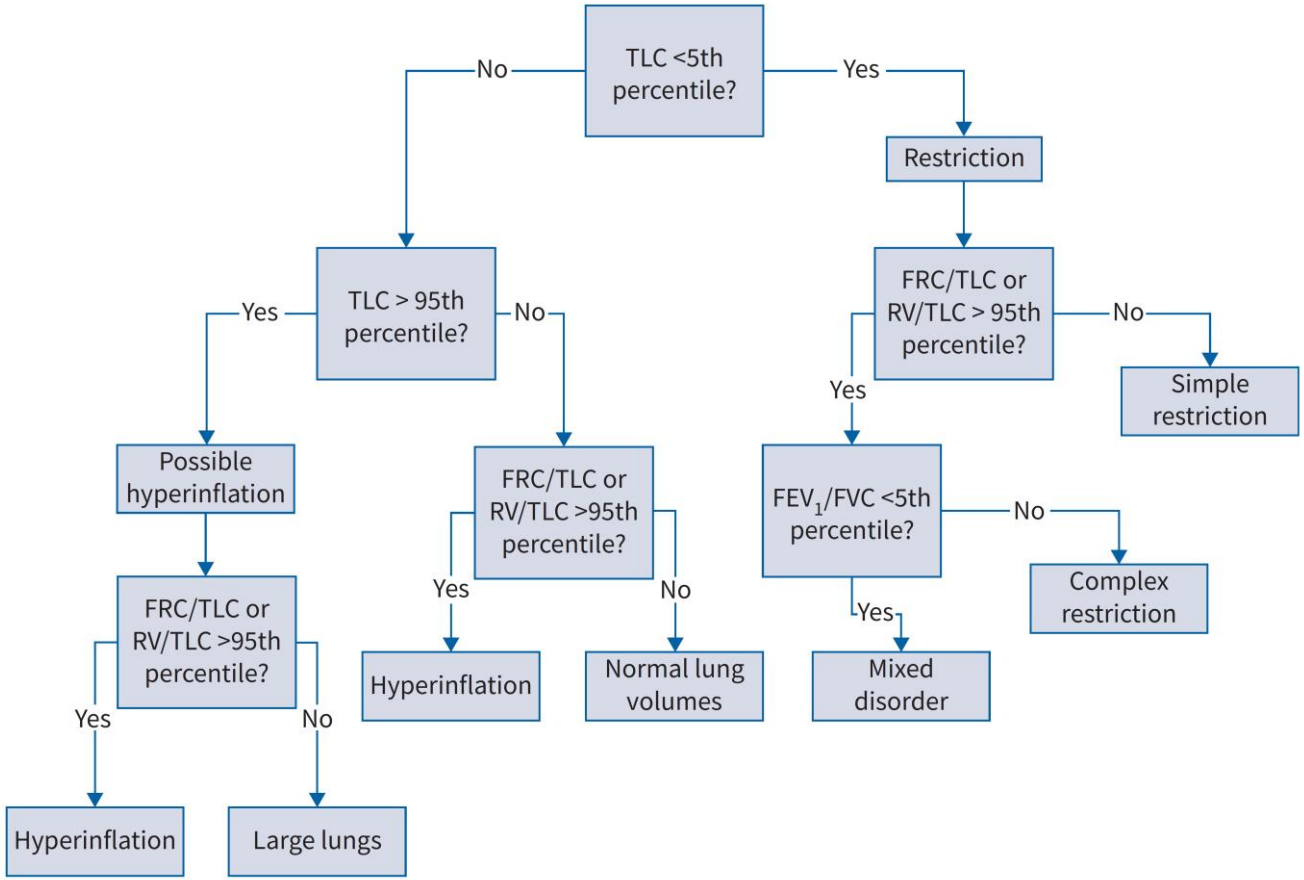
Lung Volumes – Interpretation

TABLE 7 Classification of ventilatory impairments defined by lung volumes

	TLC	FRC	RV	FRC/TLC	RV/TLC	Comments
Large lungs	↑	↑	↑	Normal	Normal	Normal variant above ULN
Obstruction	Normal/↑	Normal/↑	↑	Normal/↑	↑	Hyperinflation if FRC/TLC and RV/TLC elevated; gas trapping if only RV/TLC elevated (*e.g.* COPD)
Simple restriction	↓	↓	↓	Normal	Normal	*e.g.* ILD
Complex restriction [156]	↓	↓	Normal/↑	Normal	↑	When FEV_1/FVC is normal, complex refers to the process contributing to a restrictive process that disproportionally reduces FVC relative to TLC (*e.g.* small airway disease with gas trapping and obesity)
Mixed disorder	↓	Normal/↓	Normal/↑	Normal/↑	Normal/↑	Typically, FEV_1/FVC is reduced (*e.g.* combined ILD and COPD)
Muscle weakness	↓	Normal/↓	↑	↑	↑	When effort appears sufficient; TLC is reduced especially with diaphragm weakness; RV is increased especially with expiratory muscle weakness
Suboptimal effort	↓	Normal	↑	↑	↑	Especially when effort appears insufficient
Obesity	Normal/↓	↓	Normal/↑	Normal/↓	Normal/↑	ERV low; reduced TLC at very high BMI (>40 $kg \cdot m^{-2}$) [37]

TLC: total lung capacity; FRC: functional residual capacity; RV: residual volume; ULN: upper limit of normal; COPD: chronic obstructive pulmonary disease; ILD: interstitial lung disease; ERV: expiratory reserve volume; BMI: body mass index.

Lung Volumes – Interpretation



The DLCO Puzzle

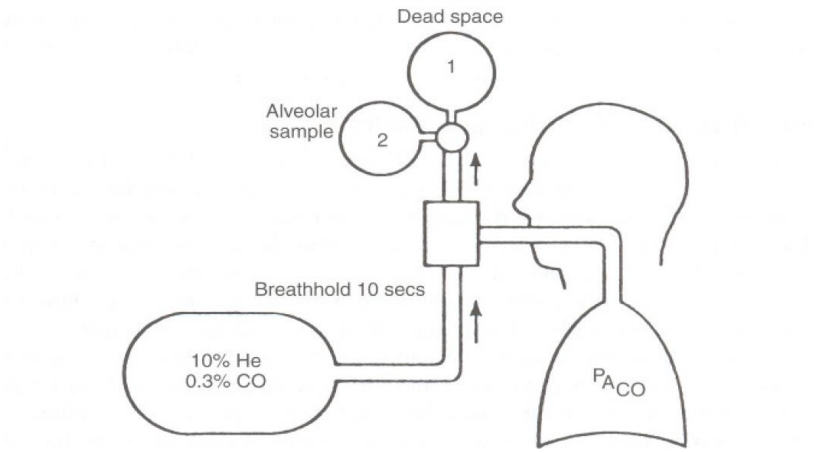
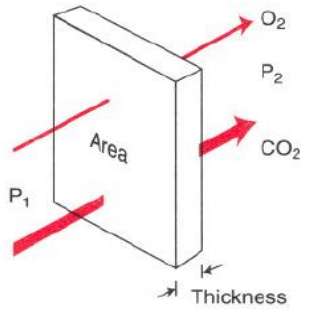


Figure 2.12. Measurement of the diffusing capacity for carbon monoxide by the single breath method. The subject takes a single breath of 0.3% CO with 10% helium, holds his or her breath for 10 seconds, and then exhales. After discarding the first 750 ml, an alveolar sample is collected and analyzed.



$$\dot{V}_{gas} \propto \frac{A}{T} \cdot D \cdot (P_1 - P_2)$$

$$D \propto \frac{Sol}{\sqrt{MW}}$$

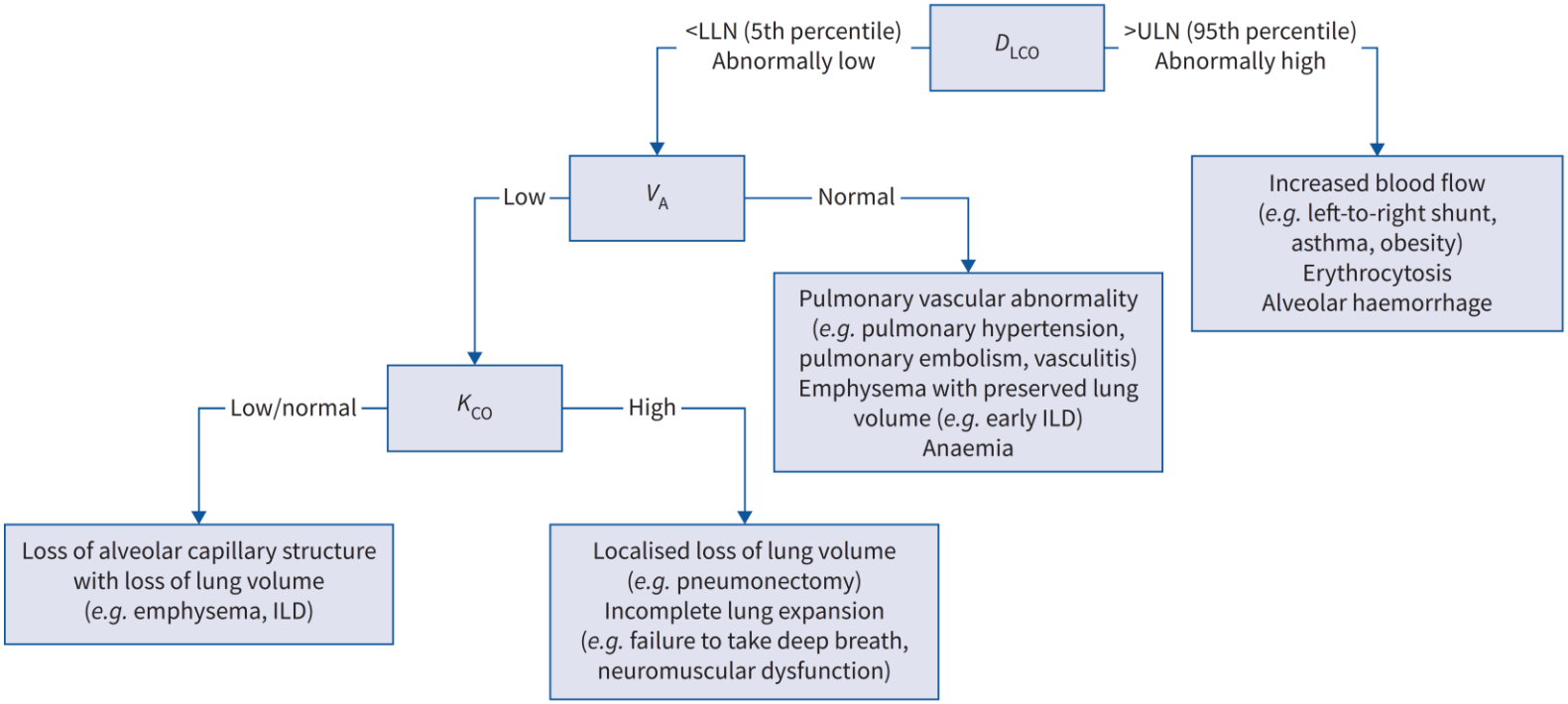
Figure 3-1. Diffusion through a tissue sheet. The amount of gas transferred is proportional to the area (A), a diffusion constant (D), and the difference in partial pressure ($P_1 - P_2$), and is inversely proportional to the thickness (T). The constant is proportional to the gas solubility (Sol) but inversely proportional to the square root of its molecular weight (MW).

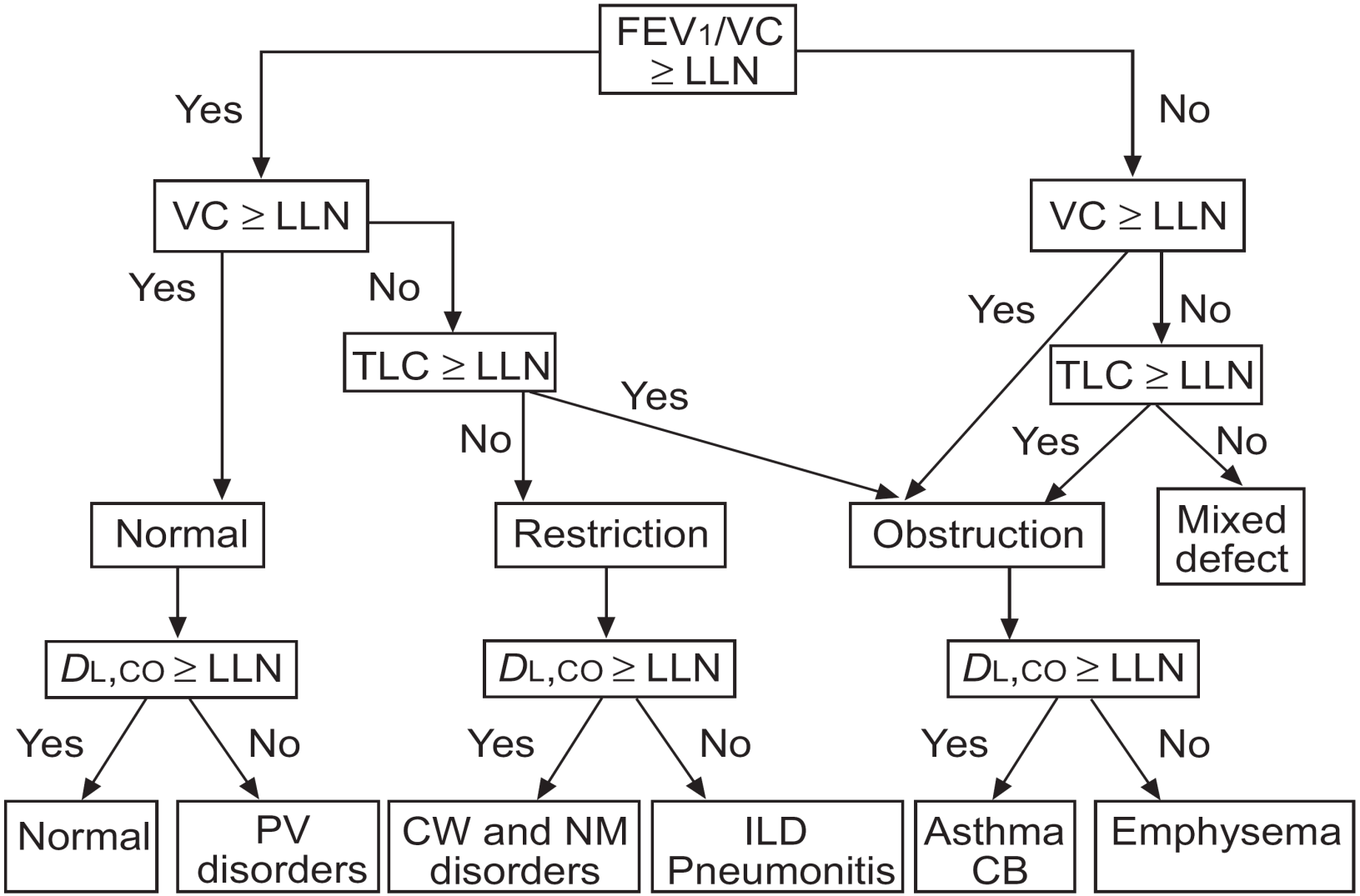
- DLCO depends on:
  - Size of the breath (VA)
  - Area of the capillary bed
  - Thickness of the capillary basement membrane
  - Blood's capacity to take up CO (hemoglobin, cardiac output)

The DLCO Puzzle

- Normal DLCO
  - Asthma/Chronic bronchitis
  - Obesity
  - Neuromuscular and chest wall diseases
- Decreased DLCO
  - Emphysema
  - ILD (fibrosis, etc)
  - Pulmonary vascular diseases
- Increased DLCO
  - Pulmonary hemorrhage
  - Heart failure (could go either way)

DLCO Interpretation





VC = Best of SVC, FVC, IVC maneuvers; PV = Pulmonary vascular;
LLN = Lower limit of normal; CW = Chest wall; CB = Chronic bronchitis
Eur Respir J 2005; 26: 948–968

PFT: Severity Assessment

Degree of Severity	FEV1 (%)
Mild	>70
Moderate	60-69
Moderately Severe	50-59
Severe	35-49
Very Severe	<35

Degree of Severity	DLCO (%)
Mild	>60
Moderate	40-59
Severe	<40

- Caveats:
  - Extremes
  - DLCO
  - Upper airway obstruction

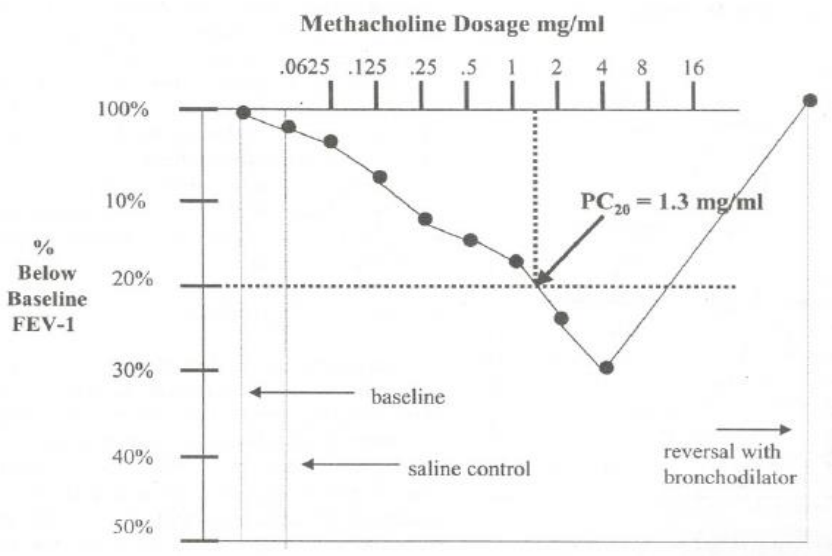
Eur Respir J 2005; 26: 948–968

Bronchoprovocation

- Indications:
  - H&P suggestive of asthma
  - PFT not diagnostic
- Contraindications:
  - Absolute
    - Severe airflow obstruction (FEV1 <50% or <1L)
    - MI or stroke within 3 months
    - Uncontrolled BP/ Aortic aneurism
    - Poor patient effort during spirometry
  - Relative
    - Moderate airflow obstruction (various definitions)
    - Pregnant/nursing mother
    - Myasthenia Gravis diagnosis/treatment

Bronchoprovocation

- Sensitive, but not specific
- PC_{20} reported
- False Negatives:
  - Inactive disease
- False Positives:
  - CHF
  - COPD
  - Rhinitis
  - Sarcoidosis



Bronchodilator Response

Does it really matter?

Bronchodilator Response

TABLE 9 Summary of the procedures relating to bronchodilator response

Procedures suggested to minimise differences within and between laboratories
- Assess lung function at baseline
- Administer salbutamol in four separate doses of 100 μg through a spacer
- Re-assess lung function after 15 min. If you want to assess the potential benefits of a different bronchodilator, use the same dose and the same route as used in clinical practice. The wait time may be increased for some bronchodilators

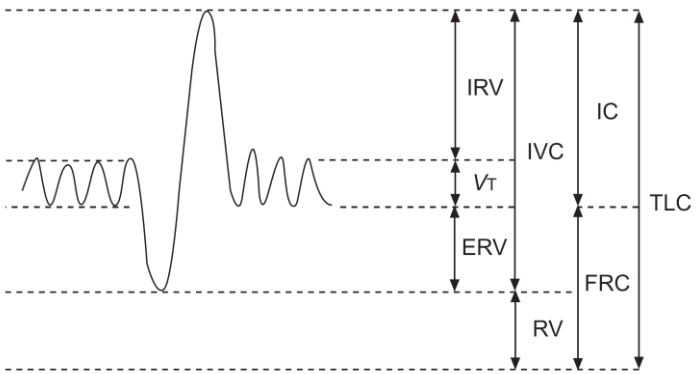
An increase in FEV_1 and/or FVC $\geqslant$12% of control and $\geqslant$200 mL constitutes a positive bronchodilator response

In the absence of a significant increase in FEV_1 and/or FVC, an improvement in lung function parameters within the tidal breathing range, such as increased partial flows and decrease of lung hyperinflation, may explain a decrease in dyspnoea

The lack of a bronchodilator response in the laboratory does not preclude a clinical response to bronchodilator therapy

Eur Respir J 2005; 26: 948–968

RV/TLC Ratio



- RV = TLC – VC
- RV/TLC = 1 – VC/TLC
  - VC could be decreased due to dynamic airway collapse
  - RV/TLC elevation is another sign of obstruction

MIP & MEP

- MIP = Maximum inspiratory pressure
- MEP = Maximum expiratory pressure
  - Used to assess respiratory muscle strength
  - Technician and patient-dependent
  - Normal values debatable
  - <50% predicted to indicates abnormality
  - >25% change is considered significant

Not a terribly valuable test

Summary

- Evaluate the quality of the test
- Scan for abnormal values
- FEV1/FVC reduced → obstruction
  - Check RV/TLC to confirm
  - Check FVL to look for additional problems
- TLC reduced → restriction
- DLCO reduced → destruction of pulmonary parenchyma or capillary bed
- Finally, correlate the PFT findings with symptoms and physical findings

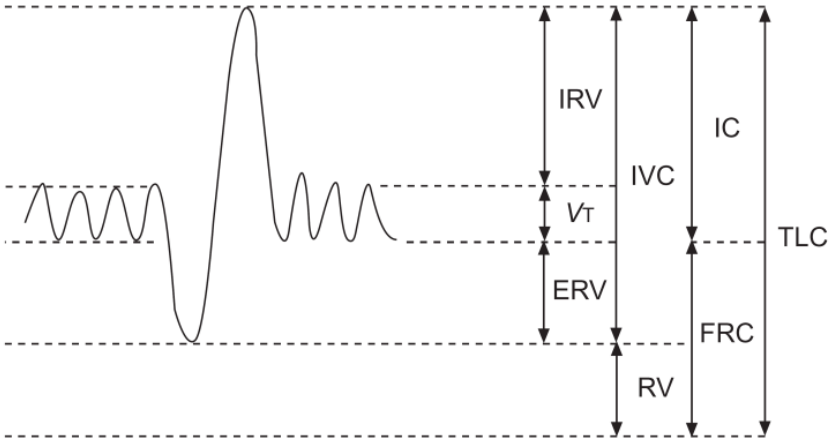
Critical Understandings in Pulmonary Function Tests

Practice Section

Warm-Up Questions

Which of the following is equal to RV?

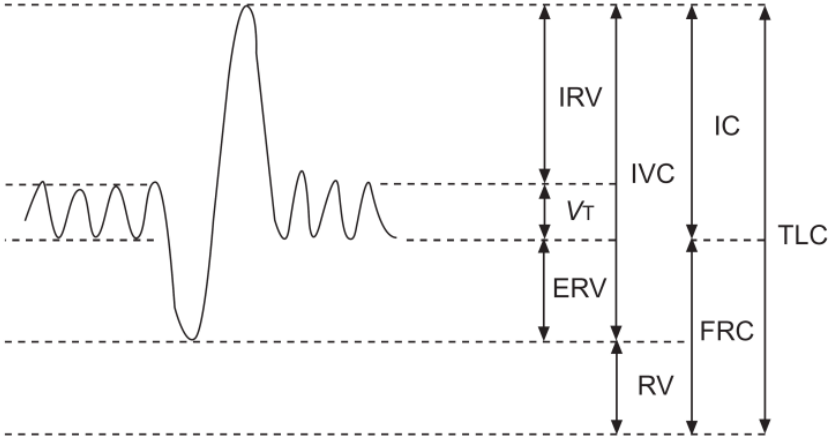
A. FRC – IRV
B. TLC – VC
C. VC – IRV
D. IC – IRV



https://www.respiratorytherapyzone.com/pft-final-exam/

Which of the following is equal to IC?

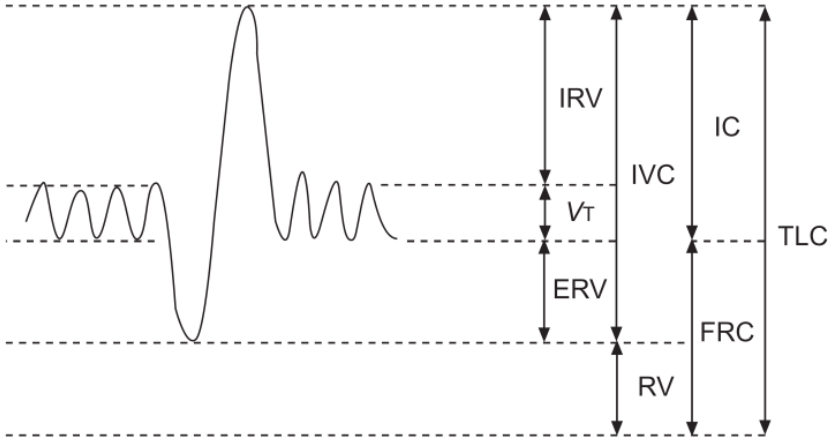
A. TLC – RV
B. VC – ERV
C. TLC – IRV
D. VT + ERV



https://www.respiratorytherapyzone.com/pft-final-exam/

A patient has a VC of 4200 ml, an FRC of 3300 ml, and ERV of 1500 ml. What is the patient's RV?

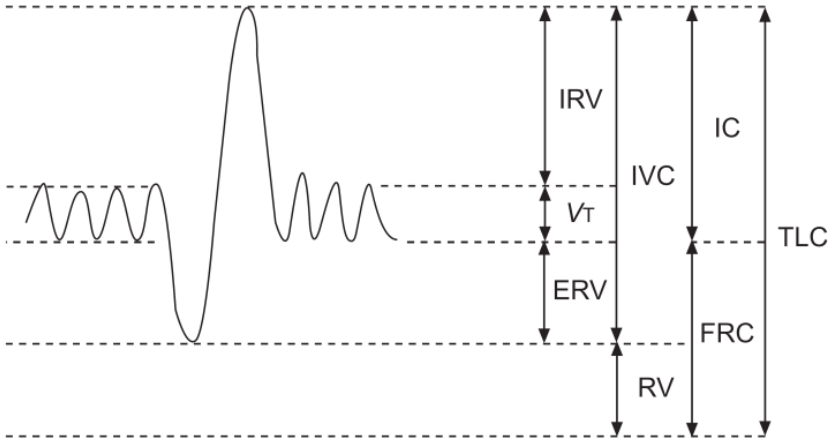
A. 2700 ml
B. 3700 ml
C. 1500 ml
D. 1800 ml



https://www.respiratorytherapyzone.com/pft-final-exam/

Results of a pulmonary function study on a patient indicate a VC of 3600 ml, an FRC of 2000 ml, and an RV of 1000 ml. What is the TLC?

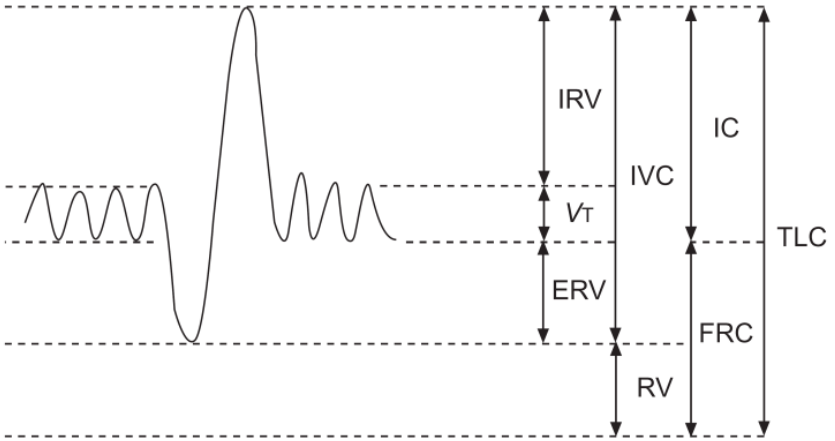
A. 5500 ml
B. 7000 ml
C. 4600 ml
D. 8600 ml



https://www.respiratorytherapyzone.com/pft-final-exam/

If VT is 650 ml, ERV is 1100 ml, and RV is 1150 ml; FRC would be equal to:

A. 3650 ml
B. 4750 ml
C. 2250 ml
D. 2900 ml



https://www.respiratorytherapyzone.com/pft-final-exam/

1. The following measurements were obtained during routine pulmonary testing:

	Measured	Reference
Vital Capacity (VC)	3 Liters	3.5-4.5 Liters
Expiratory Reserve Volume (ERV)	1 Liter	1.5-2 Liters
Functional Residual Capacity (FRC)	5 Liters	3-4 Liters

   a. Calculate TLC
   b. Discuss which, if any, respiratory disease these results would suggest
   c. Which other measurement(s) would you like to obtain to support your diagnosis?

a. TLC = VC + RV = VC + (FRC – ERV) = 7L
b. Obstructive lung disease. TLC is high, FRC is elevated, and RV seems also very elevated (reference values not given)
c. Obtain FEV1, FVC, FEV1/FVC ratio, RV/TLC ratio

FVC	80% predicted
FEV1	50% predicted
FEV1/FVC%	55
FEF 25-75%	40% predicted

What's the most likely diagnosis?

A. Silicosis
B. Kyphoscoliosis
C. Pneumothorax
D. Chronic bronchitis

https://www.respiratorytherapyzone.com/pft-final-exam/

The FRC measured by body plethysmography is 30% larger than that measured by Helium dilution. This difference is best explained by an increase in which of the following?

A. Airway resistance
B. Diffusing capacity
C. Residual volume
D. Lung compliance

https://www.respiratorytherapyzone.com/pft-final-exam/

The largest volume of gas that can be expired from a resting end-expiratory level is known as the:

A. Expiratory reserve volume
B. Inspiratory reserve volume
C. Residual volume
D. Vital capacity

https://www.respiratorytherapyzone.com/pft-final-exam/

The total amount of gas in the lungs following a maximum inspiration is described as the:

A. Total lung capacity
B. Vital capacity
C. Inspiratory reserve volume
D. Tidal volume

https://www.respiratorytherapyzone.com/pft-final-exam/

The volume of gas in the lungs that can be exhaled from end-inspiratory level during normal or tidal breathing is the:

A. Expiratory reserve volume
B. Functional residual capacity
C. Residual volume
D. Total lung capacity

https://www.respiratorytherapyzone.com/pft-final-exam/

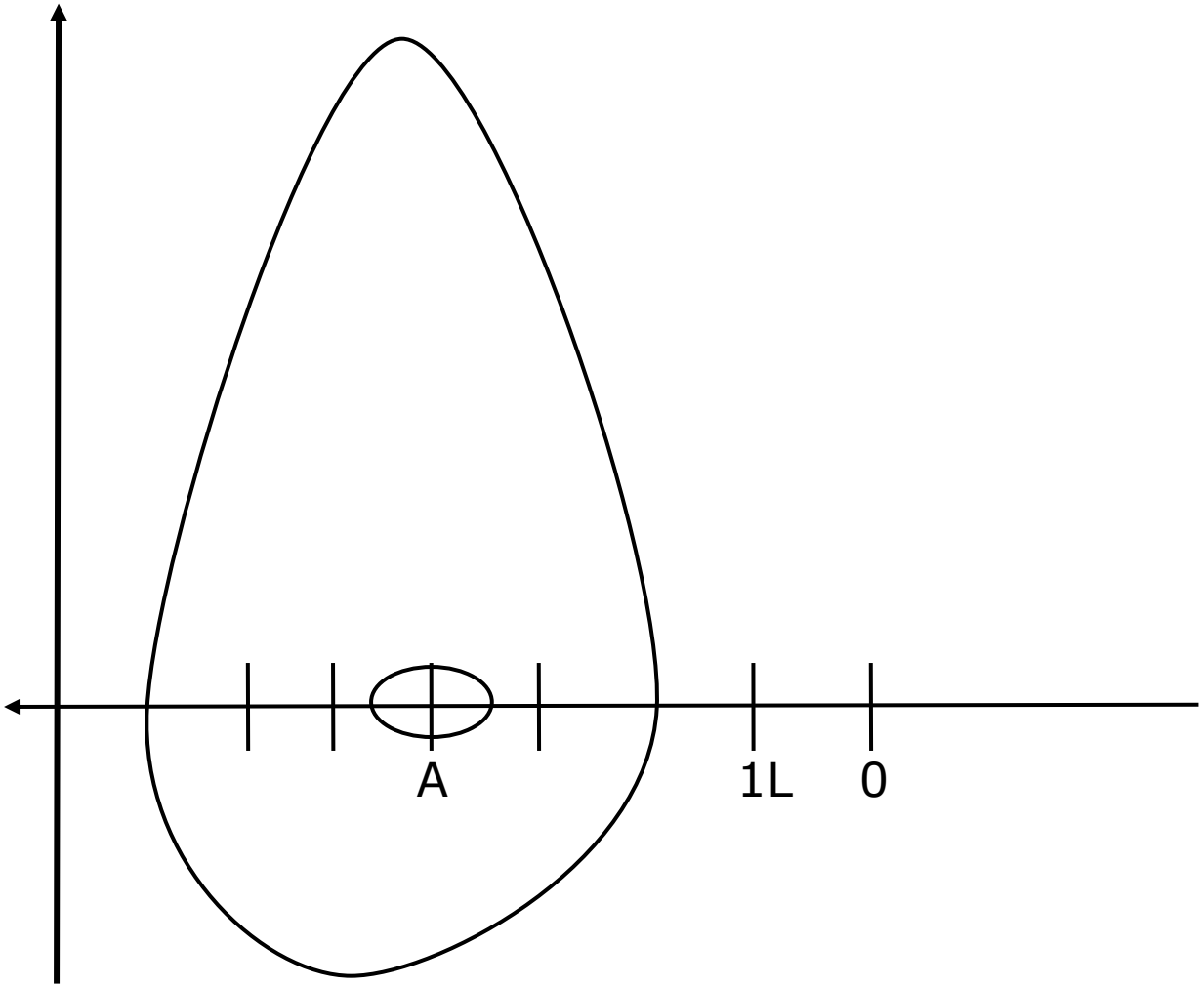
The volume of gas which remains in the lung at the end of a maximum expiration is known as:

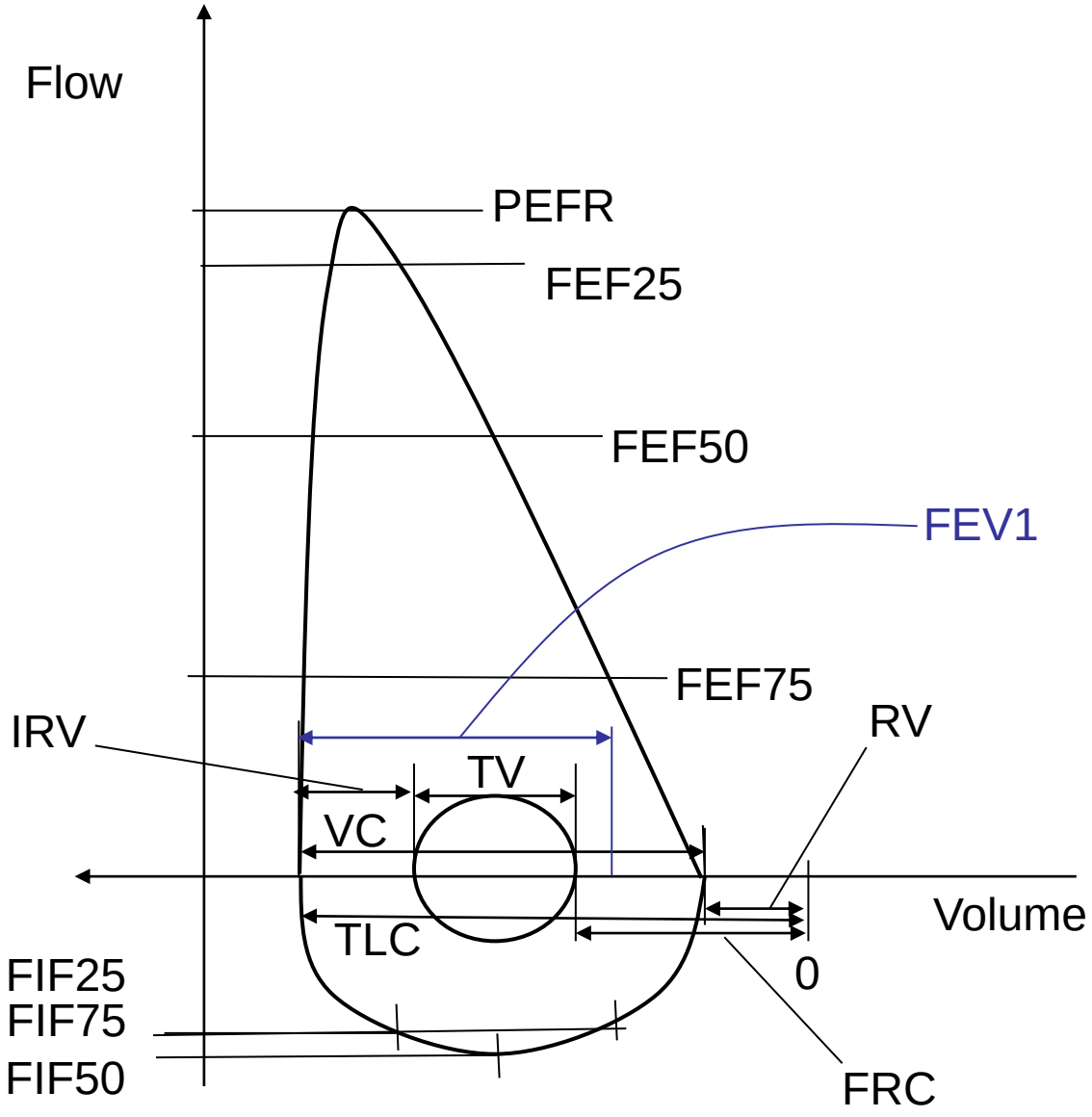
A. Residual Volume
B. Expiratory Reserve Volume
C. Functional Residual Capacity
D. Vital capacity

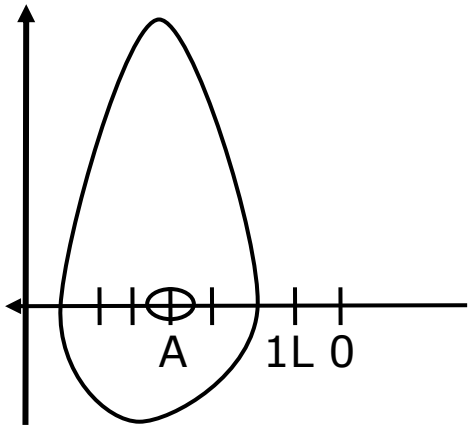
https://www.respiratorytherapyzone.com/pft-final-exam/

FVL Reading

This is a schematic representation of a FVL. Each hash mark is represents 1L, A is lung “at rest” and 0 represents an arbitrary point where lung is void of all air. Represent/calculate as many PFT parameters as possible







RV = 2L
VC = 5L
TLC = 7L
FRC = 2L
TV = 1L
ERV = 1.5L
IRV = 2.5L

PFT Reading

FEV1/VC	FEV1%	VC%	TLC%	DLCO%
0.42	20	24	150	21

- Reading:
  - Very severe obstructive lung disease with air trapping and decreased gas transfer
- Diagnosis:
  - Severe COPD with large bullae

FEV1/VC	FEV1%	VC%	TLC%	DLCO%
0.7	69	83	85	112

- Reading:
  - Moderate obstructive lung disease with normal gas transfer
- Diagnosis:
  - Asthma

FEV1/VC	FEV1%	VC%	TLC%	DLCO%
0.88	58	51	55	23

- Reading:
  - Moderately severe restrictive lung disease with severely decreased gas transfer
- Diagnosis:
  - Hypersensitivity pneumonitis

FEV1/VC	FEV1%	VC%	TLC%	DLCO%
0.92	62	60	65	42

- Reading:
  - Moderate restrictive lung disease with moderate decrease in gas transfer
- Diagnosis:
  - Sarcoidosis

FEV1/VC	FEV1%	VC%	TLC%	DLCO%
0.55	52	65	62	20

- Reading:
  - Moderately severe mixed lung disease with severely reduced gas transfer
- Diagnosis:
  - COPD with IPF

FEV1/VC	FEV1%	VC%	TLC%	DLCO%
0.91	50	54	60	57
0.84	45	50	55	112

- Reading:
  - Severe restrictive lung disease with moderately decreased gas transfer
- Diagnosis:
  - SLE (with alveolar hemorrhage)

FEV1/VC	FEV1%	VC%	TLC%	DLCO%
0.85	60	60	63	75

- Reading:
  - Moderate restrictive lung disease with normal gas transfer
- Diagnosis:
  - Neuromuscular disease

Further (Extensive) Reading

- Stanojevic S, Kaminsky DA, Miller MR, et al.
  - ERS/ATS technical standard on interpretive strategies for routine lung function tests.
  - Eur Respir J 2022; 60: 2101499
- European Respiratory Journal 2005; 26
  - Page 153-161 General Considerations
  - Page 319-338 Standardization of Spirometry
  - Page 511-522 Standardization of Lung Volumes
  - Page 720-735 Standardization of DLCO
  - Page 948-968 Interpretation