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PULMONARY FUNCTION TESTS

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Objectives

- Identify the components of PFTs
- Describe the indications
- Develop a stepwise approach to interpretation
- Recognize common patterns
- Apply this information to insurance underwriting

The Purpose

- Provide *quantifiable, reproducible* measurement of lung function

Indications

- To evaluate patients with dyspnea, chronic cough or an abnormal chest x-ray (CXR)
- To screen individuals at risk of having pulmonary diseases
  1. Smokers
  2. Individuals in occupations with exposures to injurious substances
- To quantify the severity of disease
- To screen for unsuspected, early or asymptomatic disease
- To follow disease activity over time or in response to therapy

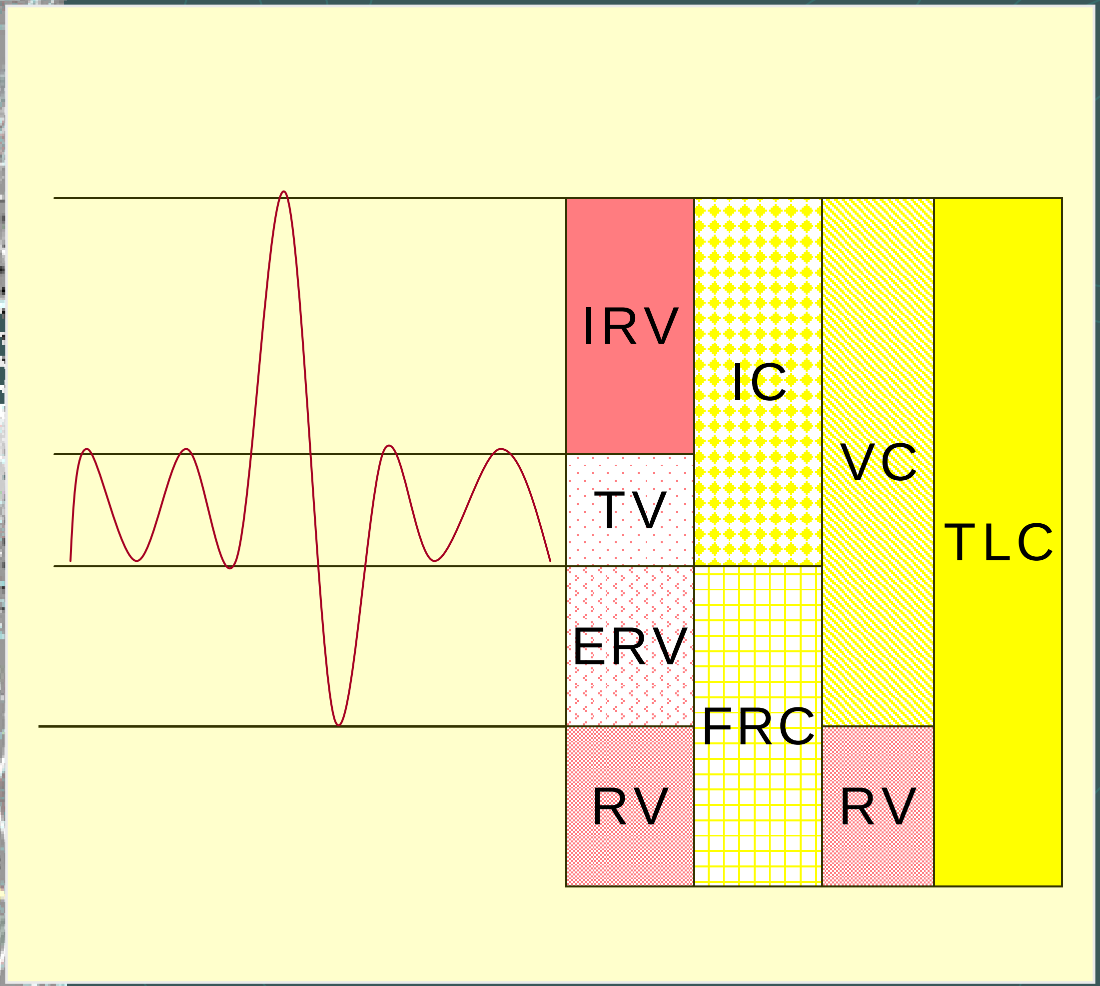
Indications

- To predict the risk of surgery
- To assess response to bronchodilator medication
- To document baseline or pre-clinical disease state for later comparison

Pulmonary Function Tests

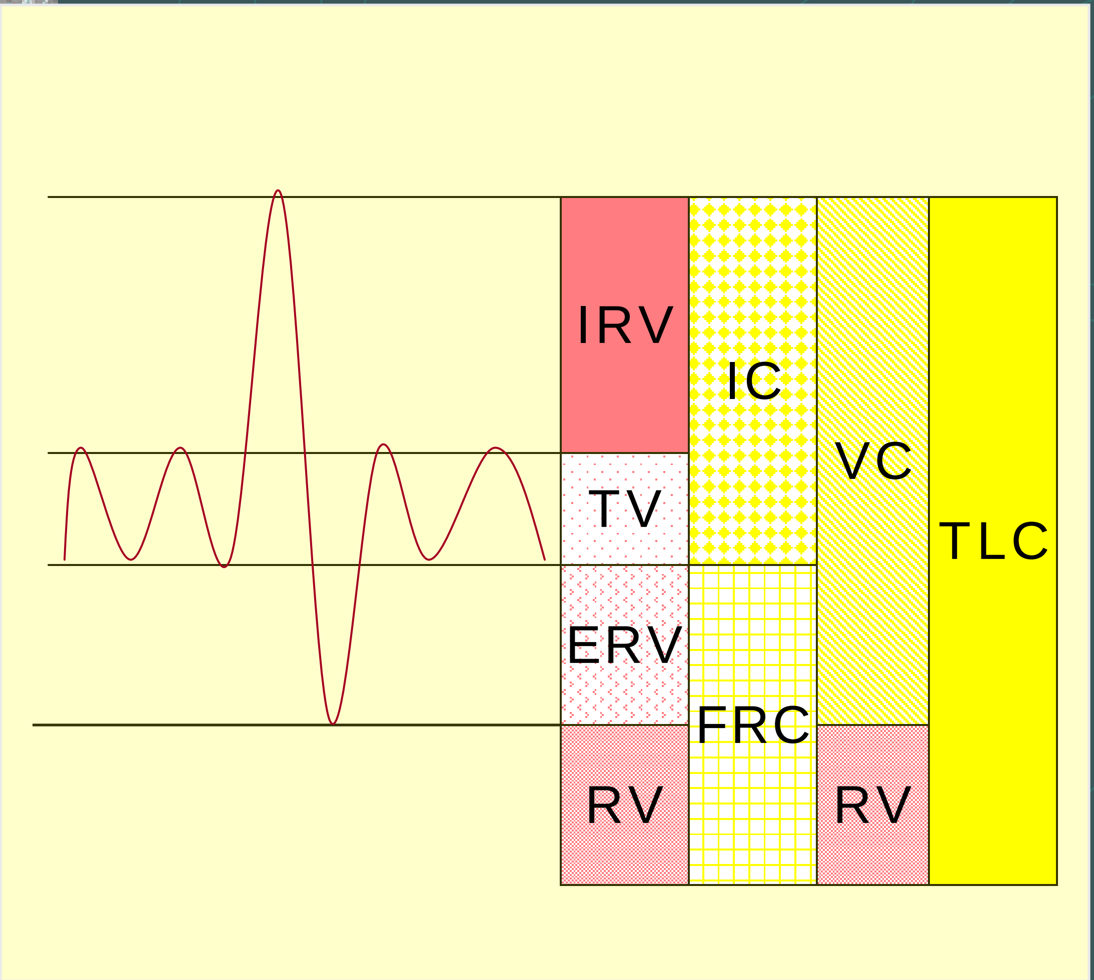
- Evaluates 1 or more major aspects of the respiratory system
  - Lung volumes
  - Airway function
  - Gas exchange

Lung Volumes



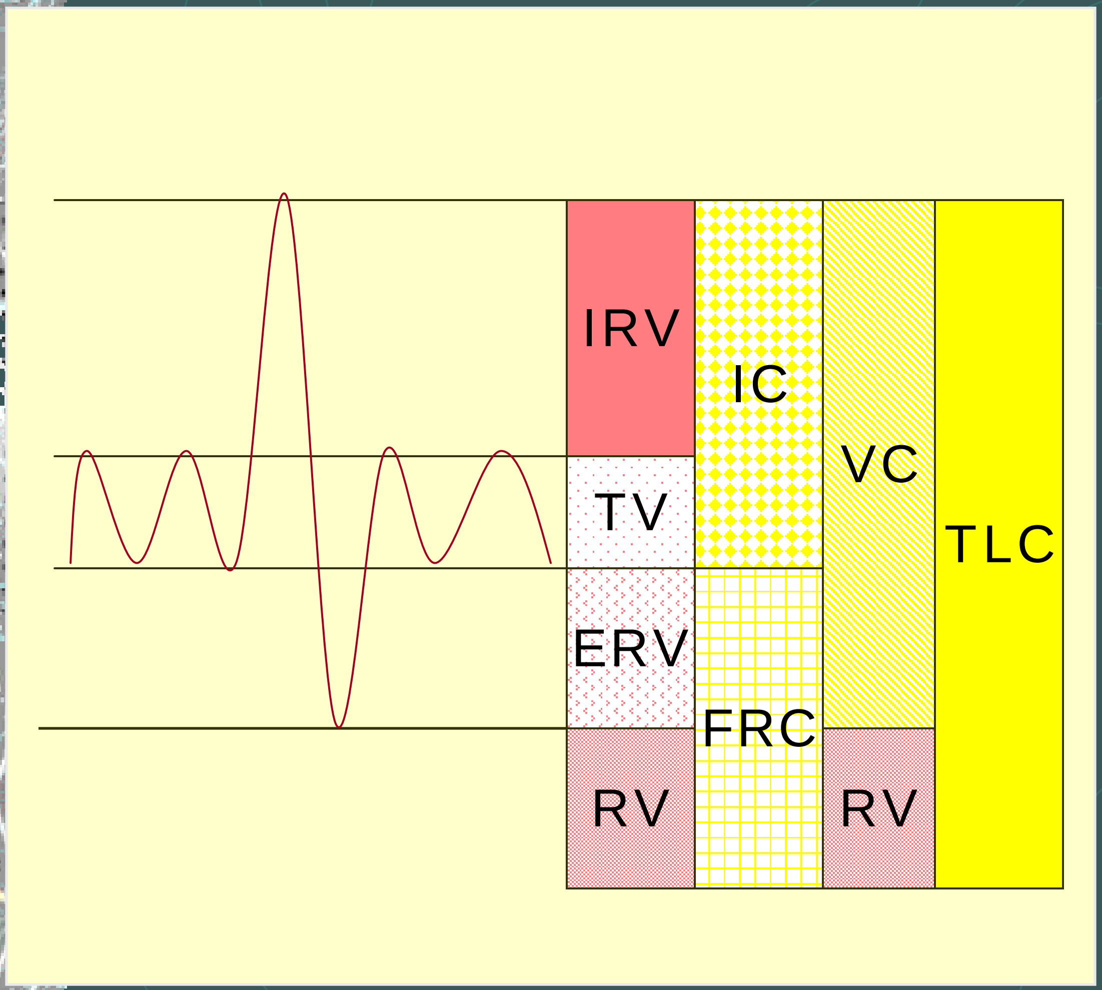
- 4 Volumes
- 4 Capacities
  - Sum of 2 or more lung volumes

Tidal Volume (TV)



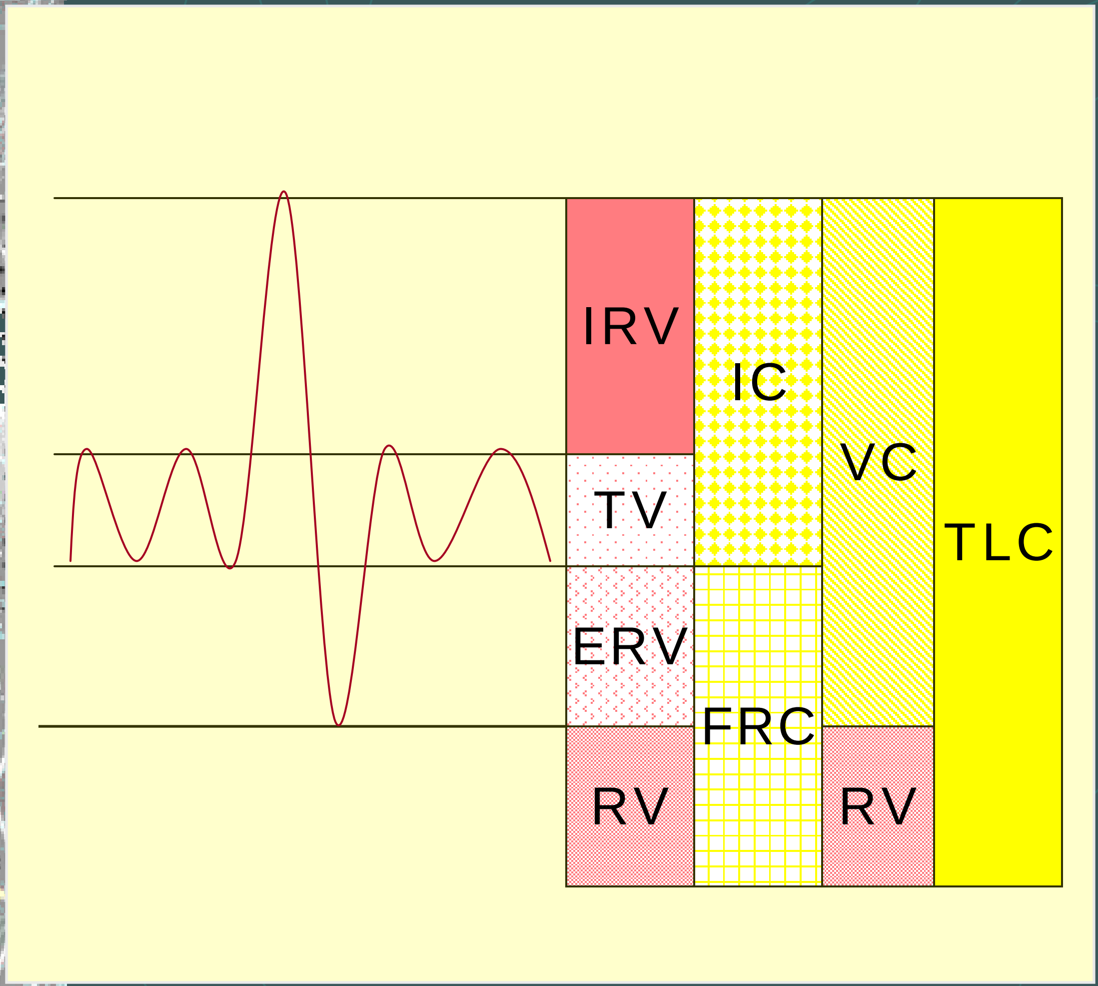
- Volume of air inspired and expired during normal quiet breathing

Inspiratory Reserve Volume (IRV)



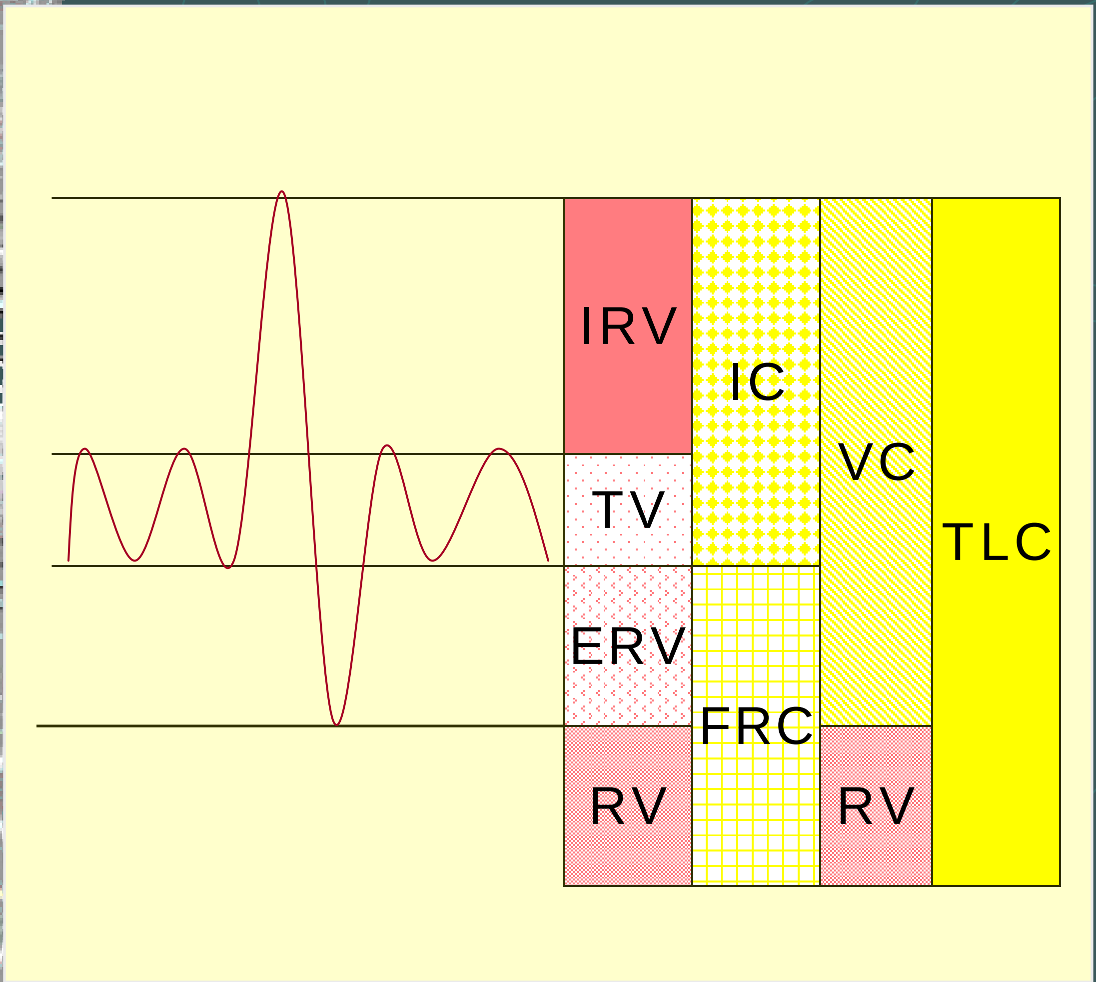
- The maximum amount of air that can be inhaled after a normal tidal volume inspiration

Expiratory Reserve Volume (ERV)



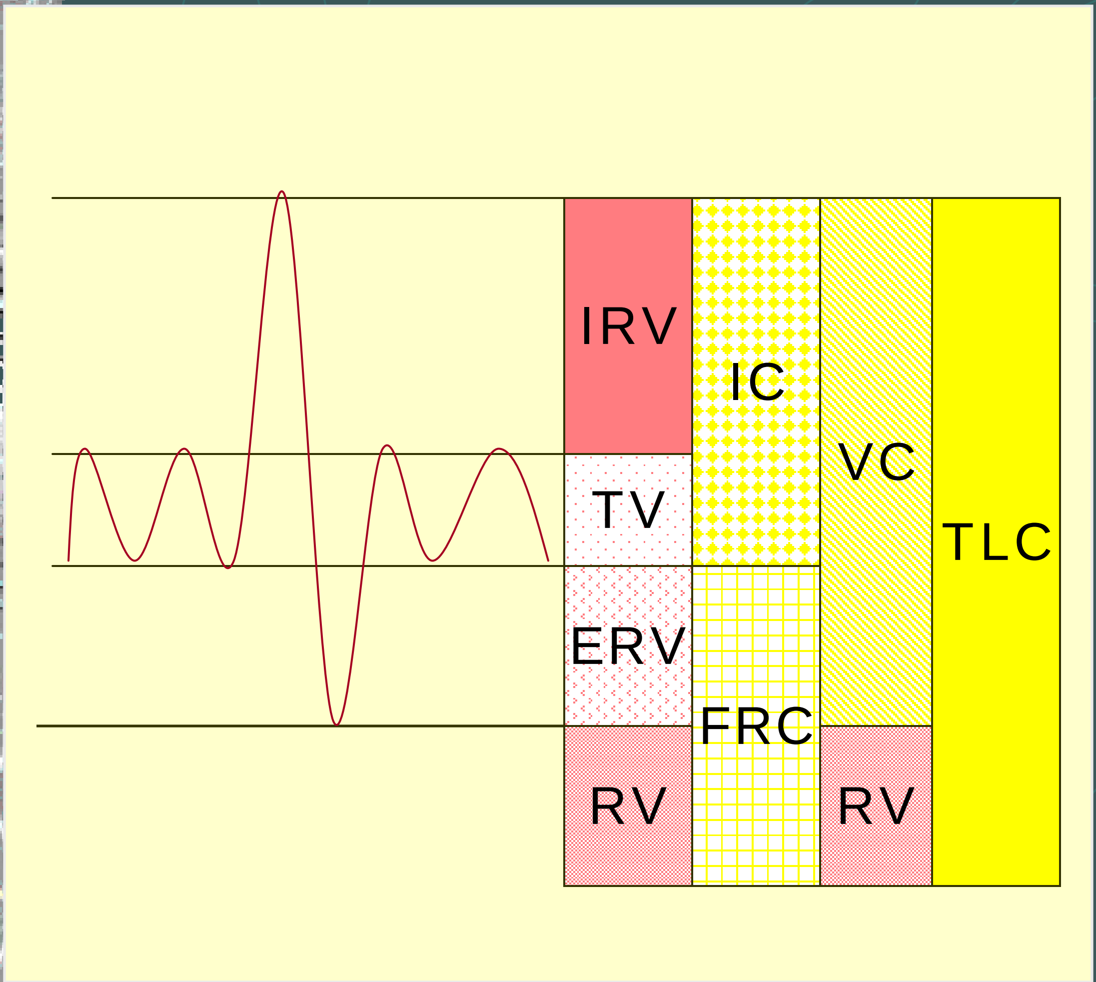
- Maximum amount of air that can be exhaled from the resting expiratory level

Residual Volume (RV)



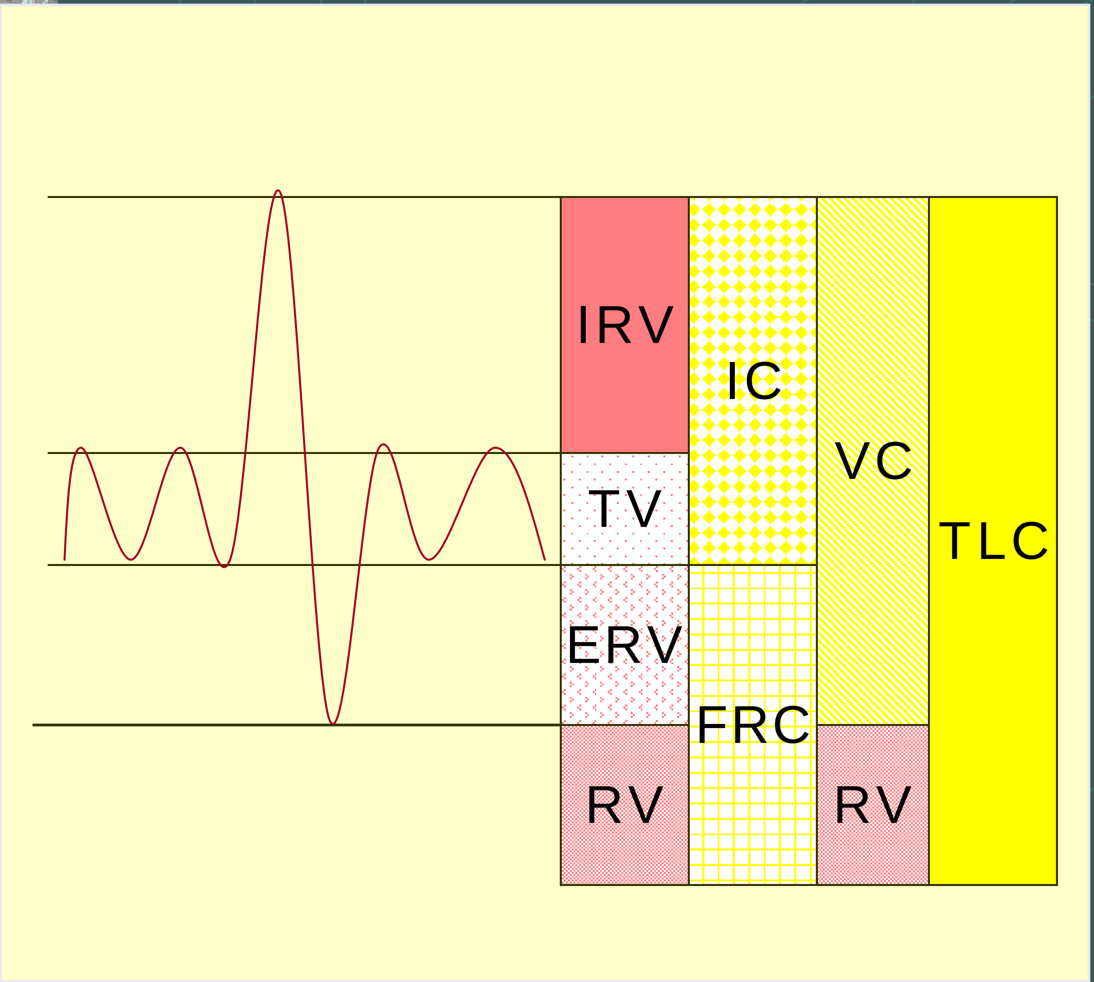
- Volume of air remaining in the lungs at the end of maximum expiration

Vital Capacity (VC)



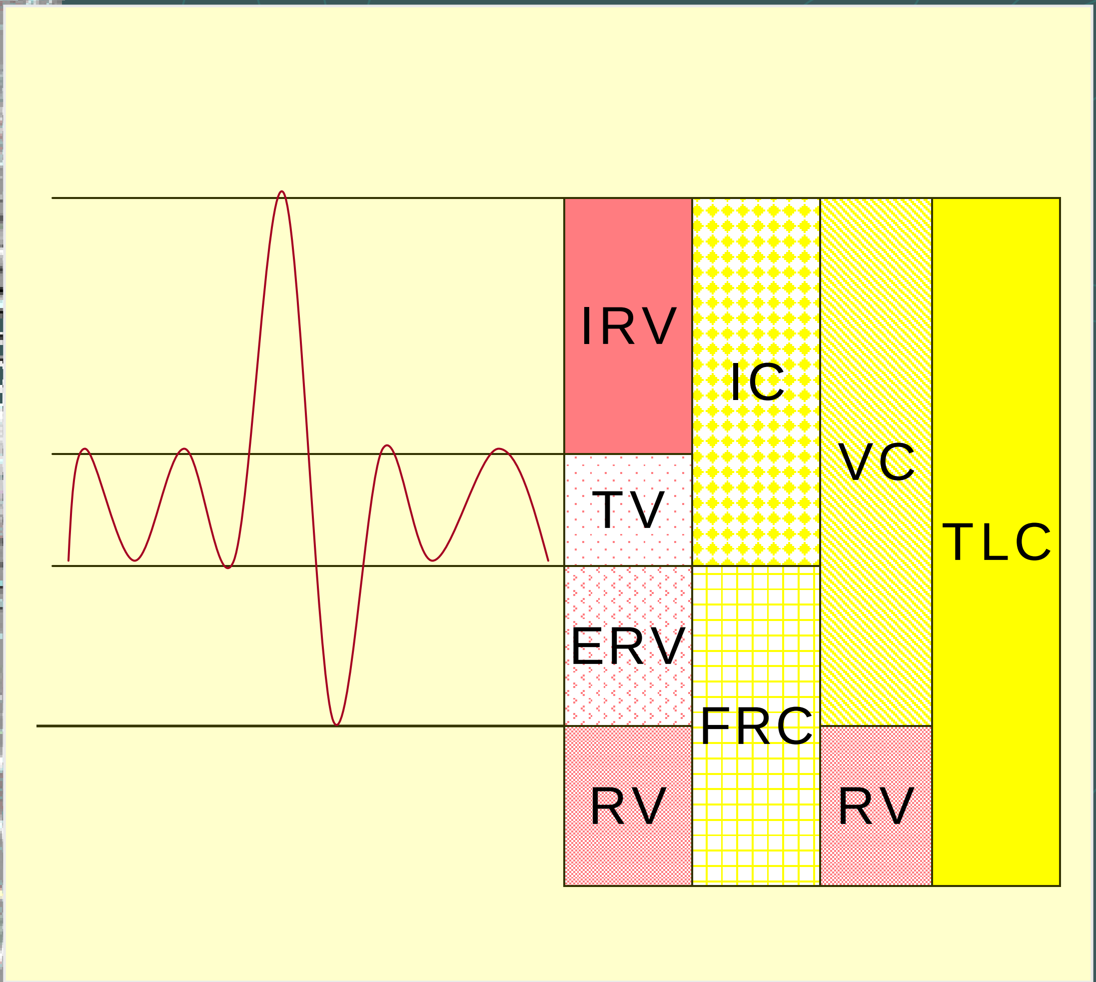
- Volume of air that can be exhaled from the lungs after a maximum inspiration
- FVC: when VC exhaled forcefully
- SVC: when VC is exhaled slowly
- VC = IRV + TV + ERV

Inspiratory Capacity (IC)



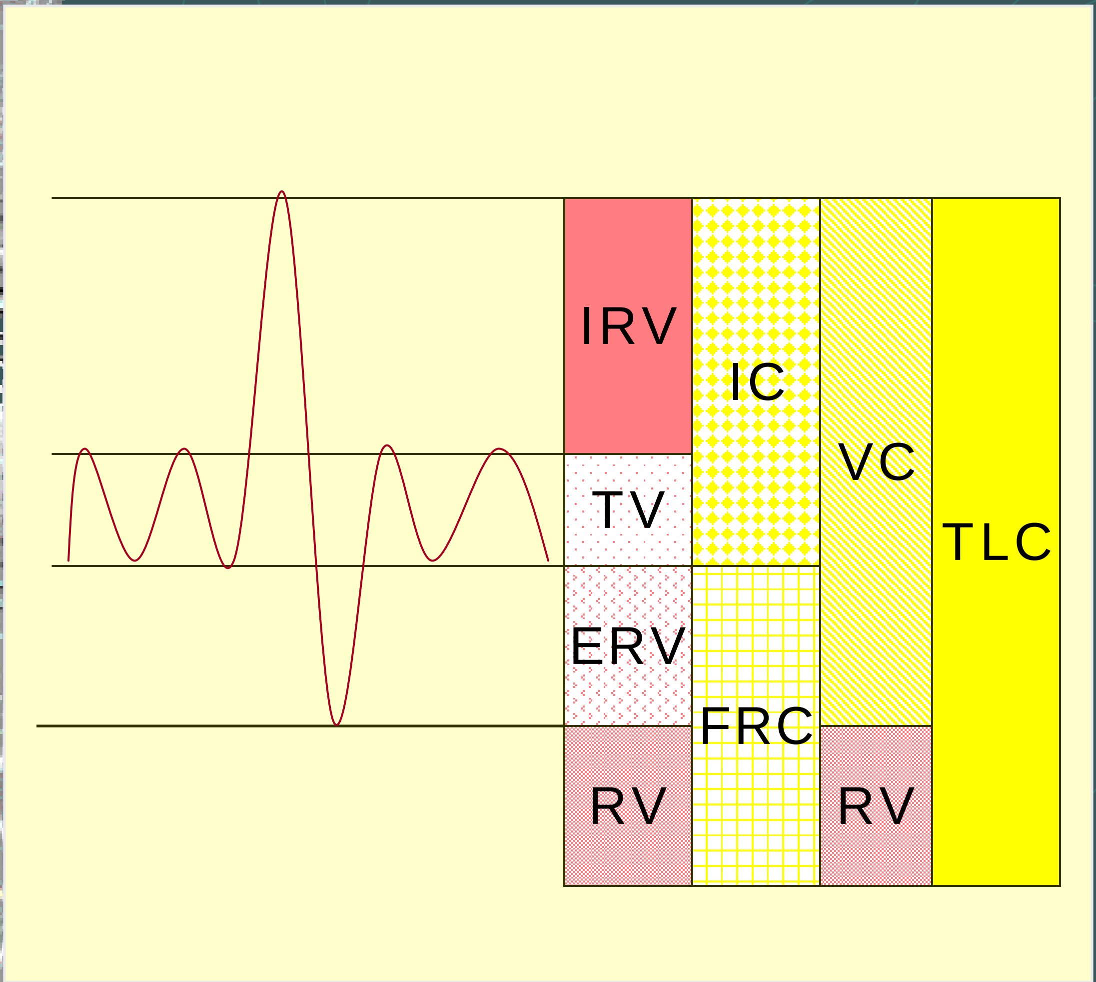
- Maximum amount of air that can be inhaled from the end of a tidal volume
- IC = IRV + TV

Functional Residual Capacity (FRC)



- Volume of air remaining in the lungs at the end of a TV expiration
- FRC = ERV + RV

Total Lung Capacity (TLC)

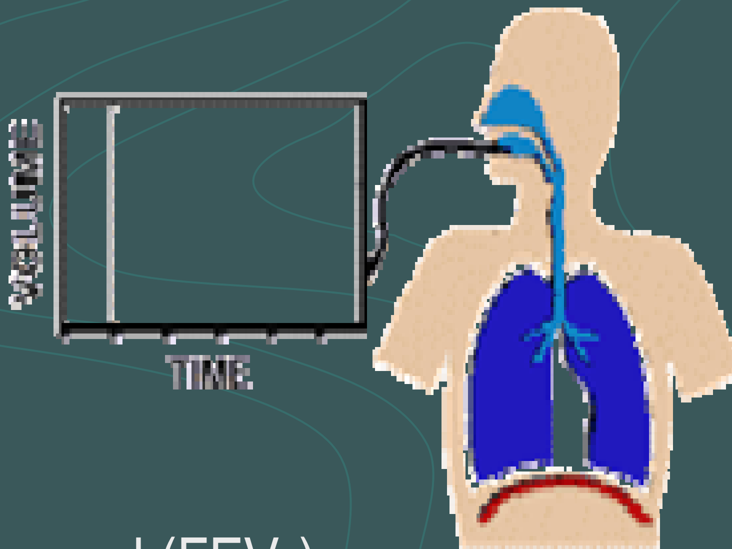


- Volume of air in the lungs after a maximum inspiration
- TLC = IRV + TV + ERV + RV

Spirometry

- Measurement of the pattern of air movement into and out of the lungs during controlled ventilatory maneuvers.

Spirometry



- Measures flow, volumes
- Can determine:
  - Forced expiratory volume in one second (FEV_1)
  - Forced vital capacity (FVC)
  - FEV_1/FVC
  - Forced expiratory flow 25%-75% (FEF_{25-75})

Importance

- Patients and physicians have inaccurate perceptions of severity of airflow obstruction and/or severity of lung disease by physical exam
- Provides objective evidence in identifying patterns of disease

Factors That Affect Lung Volumes

- Age

  FVC and flow rates decline with age

- Sex

  Most pulmonary function values are lower in female than male

- Height

  All spirometric measurements increase with body weight

- Weight

All spirometric results are positively correlated with weight to the extent that increased weight means growth of muscle mass. Beyond this (in obesity) spirometric values (and lung values specially ERV) decrease with greater weight.

- Race

FEV1 and FVC are greater in whites compared with blacks and Asians

Preparation of the patient

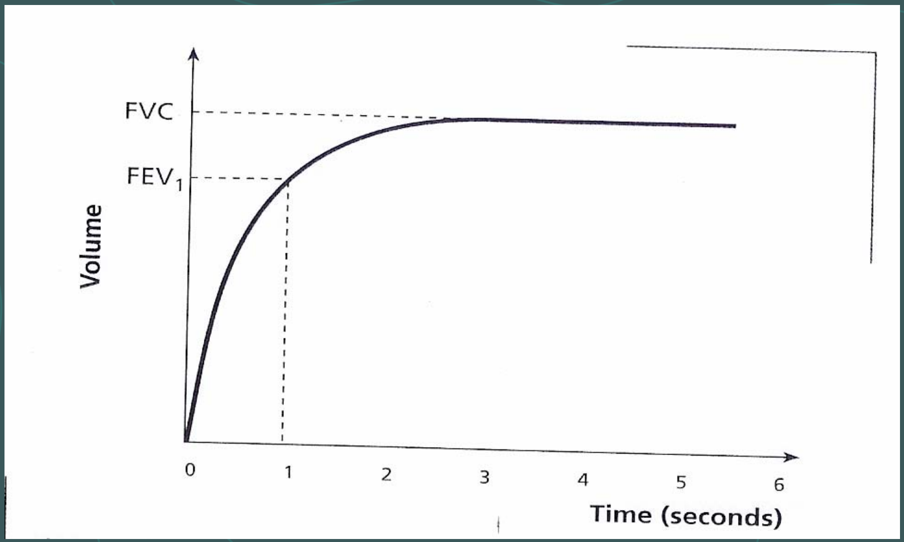
- The patient's condition should be stable (ie at least 6 weeks since an exacerbation).
- Before a bronchodilator reversibility test the patient should stop their short acting $\beta 2$ agonist for 6 hours or long acting bronchodilator for 12 hours and theophyllines for 24 hours.

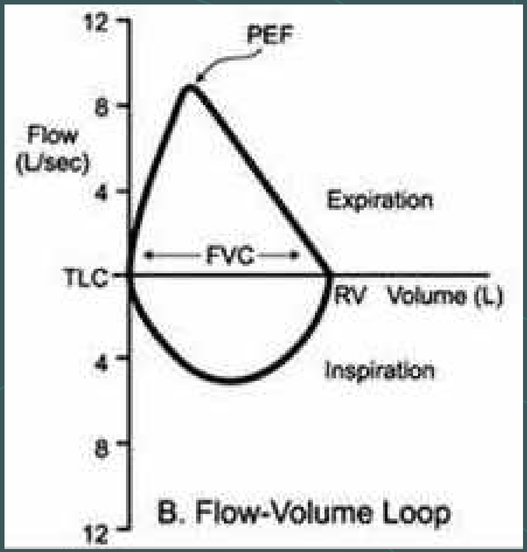
Performing the Test

1. Stand or sit up straight (The patient places a clip over the nose)
2. Get a good seal around mouthpiece of the spirometer
3. Inhale maximally
4. Blow out as hard and as fast as possible and count for at least 6 seconds.
5. Record the best of three trial

1. Volume Time Graph

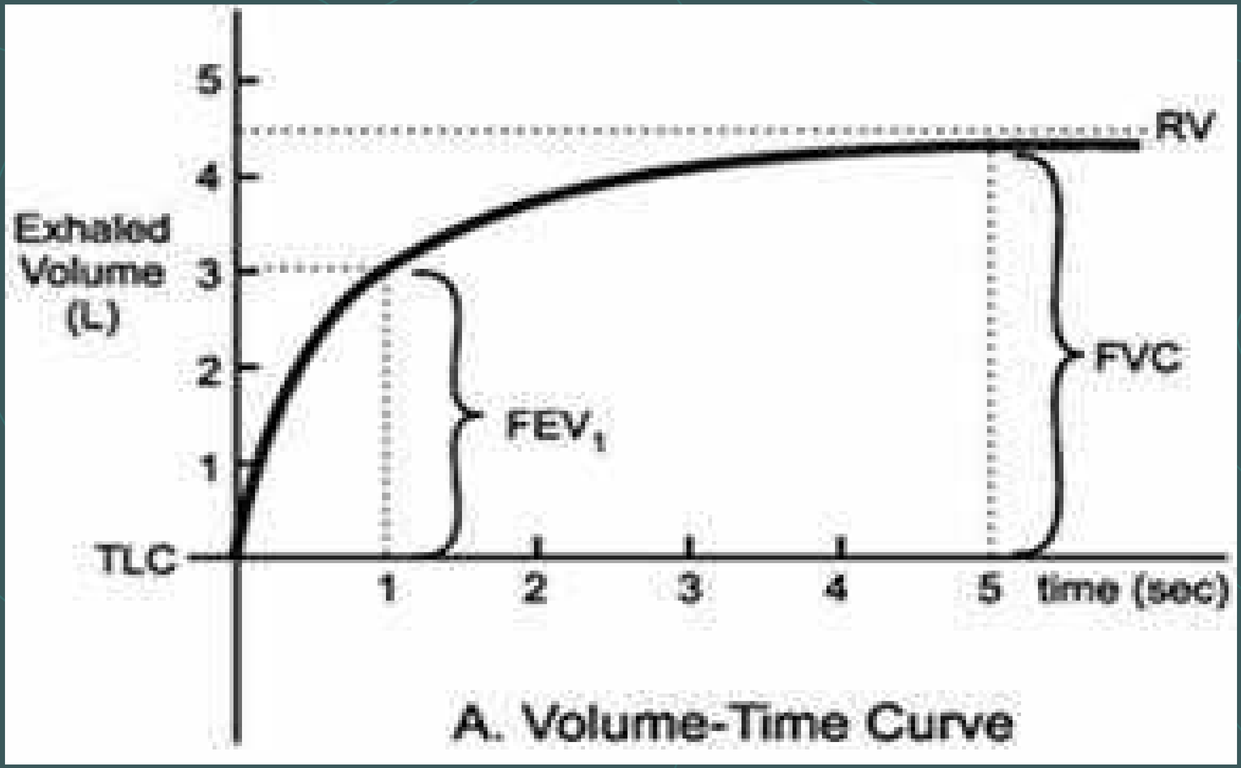
2. Flow-volume loops





Volume Time Graph

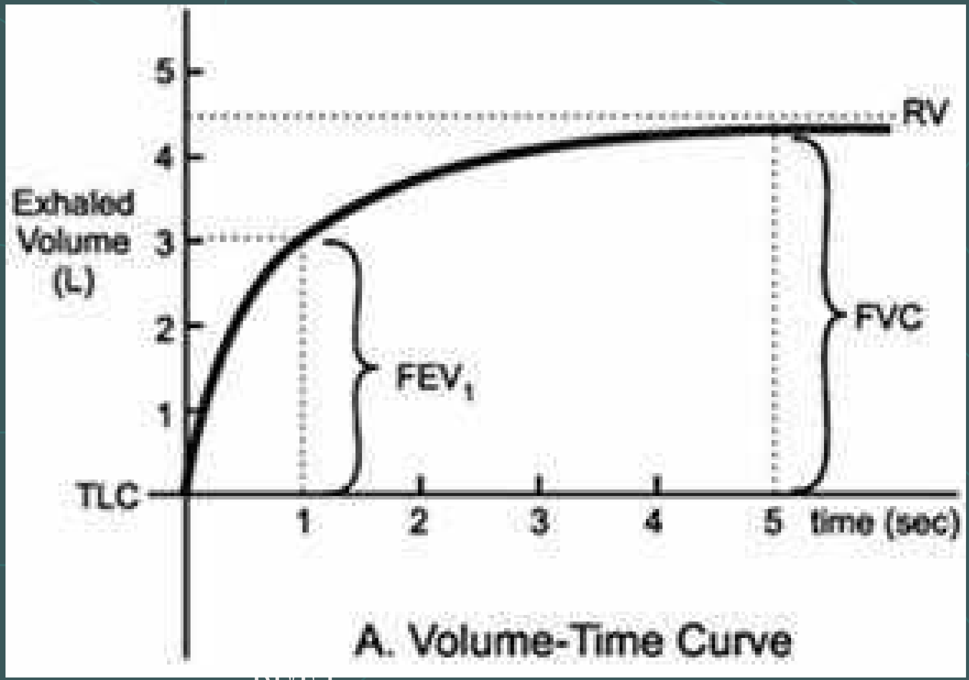
The volume is plotted against the time, it displays the expiration.



1. FVC
2. FEV1
3. FEV1/FVC
4. FEF25%
5. FEF75%

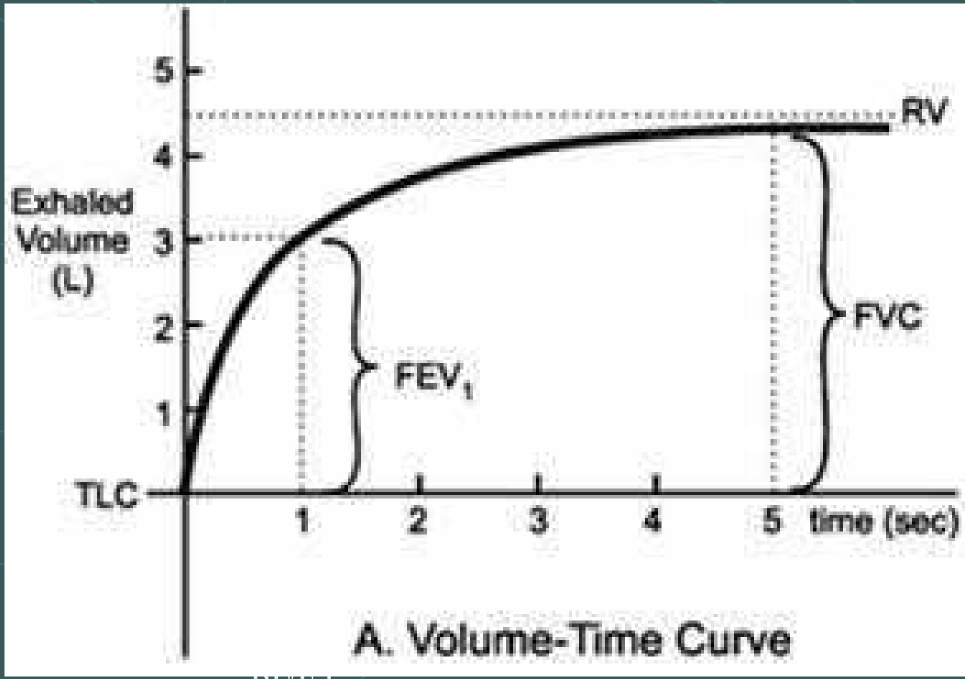
Forced Vital Capacity (FVC)

The total amount of air expired as quickly as possible after taking the deepest possible breath.



FEV1 :

Volume of air which can be forcibly exhaled from the lungs in the first second of a forced expiratory maneuver.

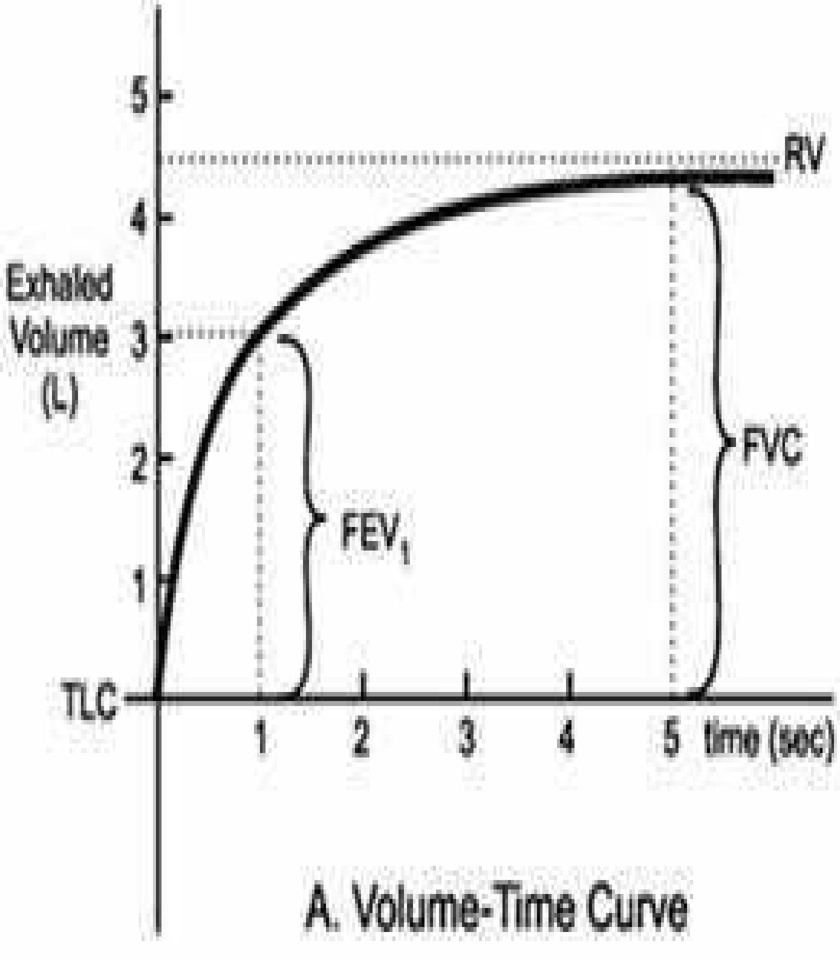


FEV1/FVC

Ratio of *FEV1* to *FVC* :

It indicates what percentage of the total *FVC* was expelled from the lungs during the first second of forced exhalation

This value is critically important in the diagnosis of obstructive and restrictive diseases



- Spirometry indicates the presence of an abnormality if any of the following are recorded:
  - FEV1 <80% predicted normal
  - FVC <80% predicted normal
  - FEV1/FVC ratio <0.7

FEF25%

Amount of air that was forcibly expelled in the first 25% of the total forced vital capacity test.

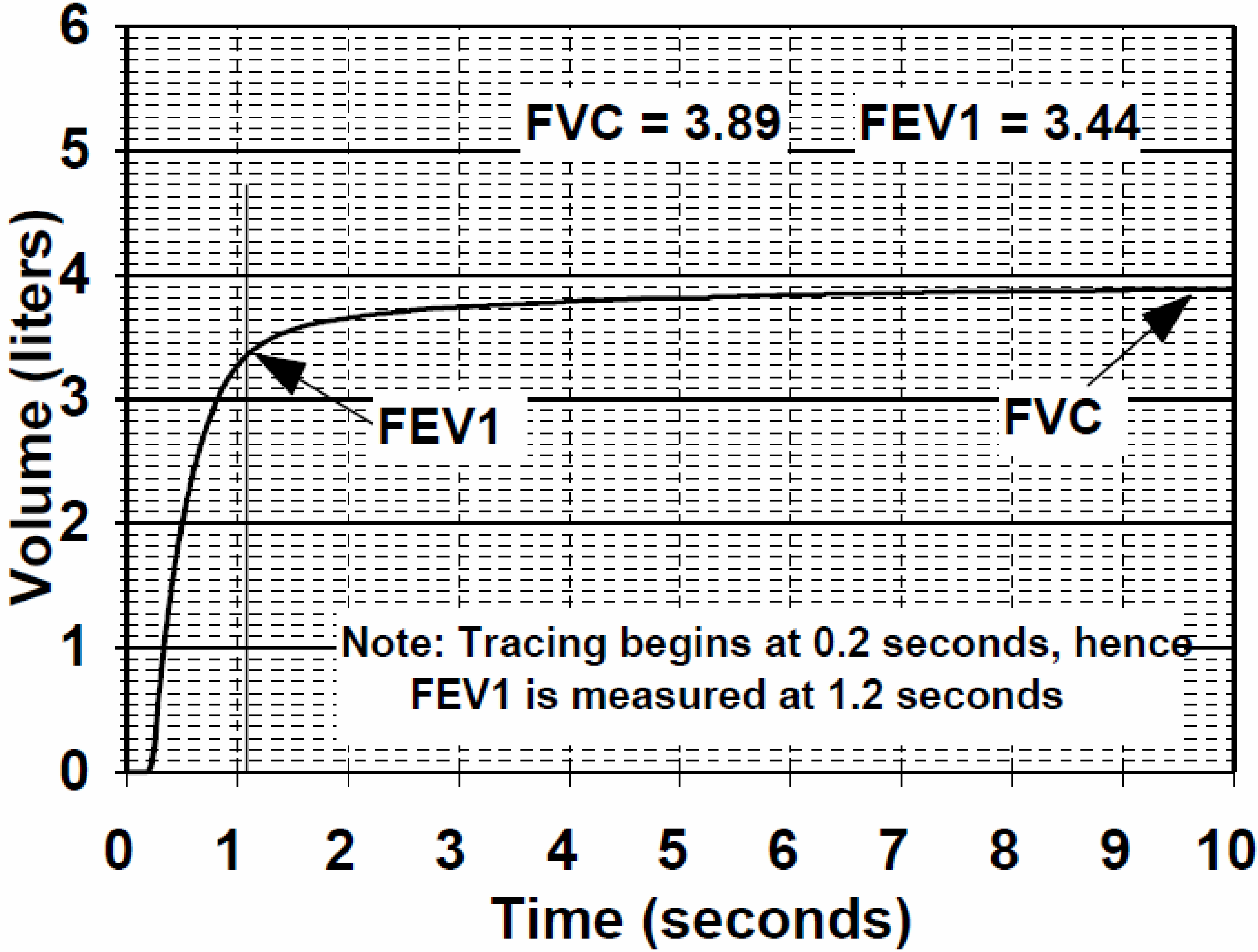
FEF75%

The amount of air expelled from the lungs during the first (75%) of the forced vital capacity test.

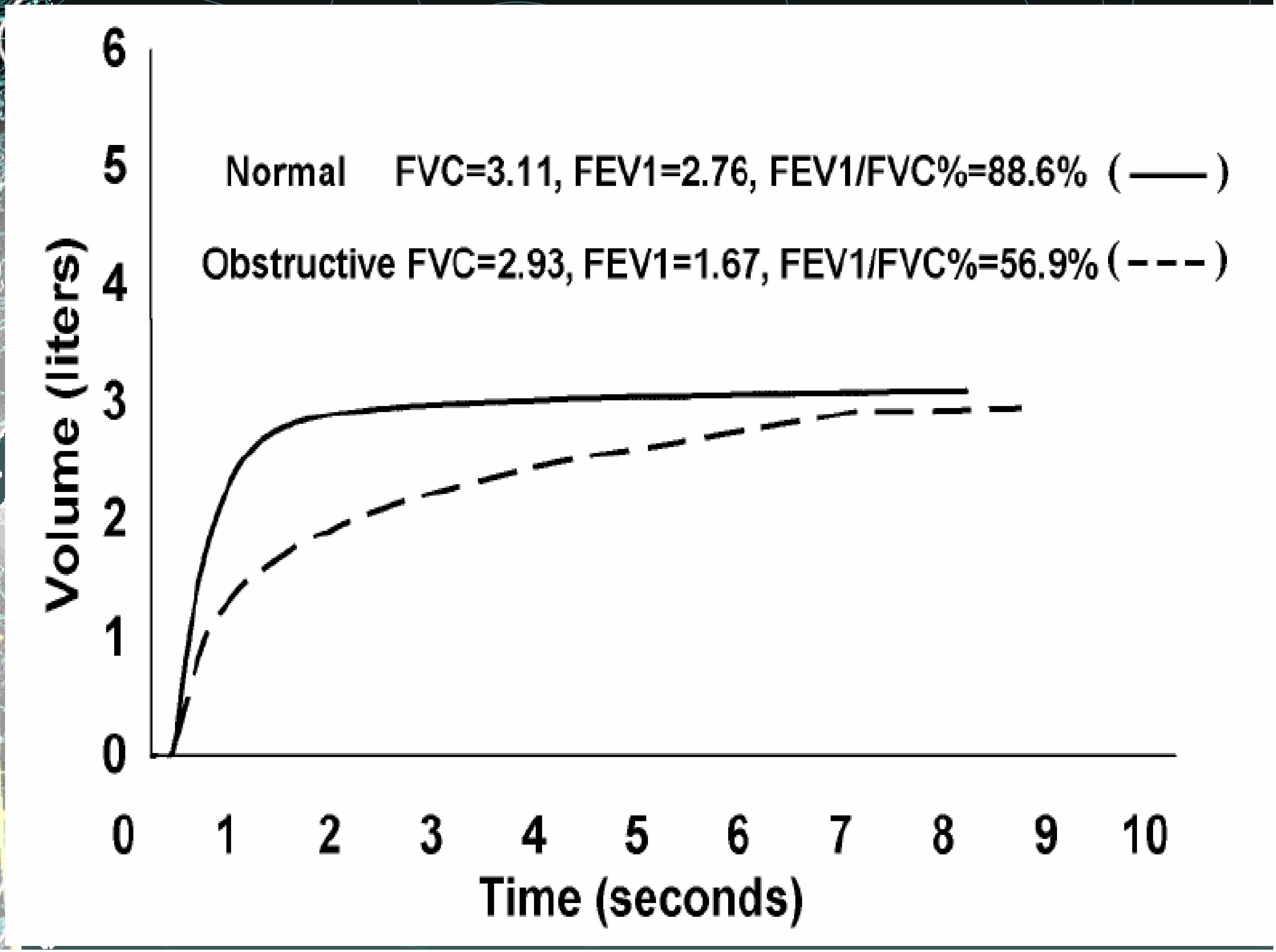
FEF25%-75%

The amount of air expelled from the lungs during the middle half of the forced vital capacity test.

Volume Time Graph



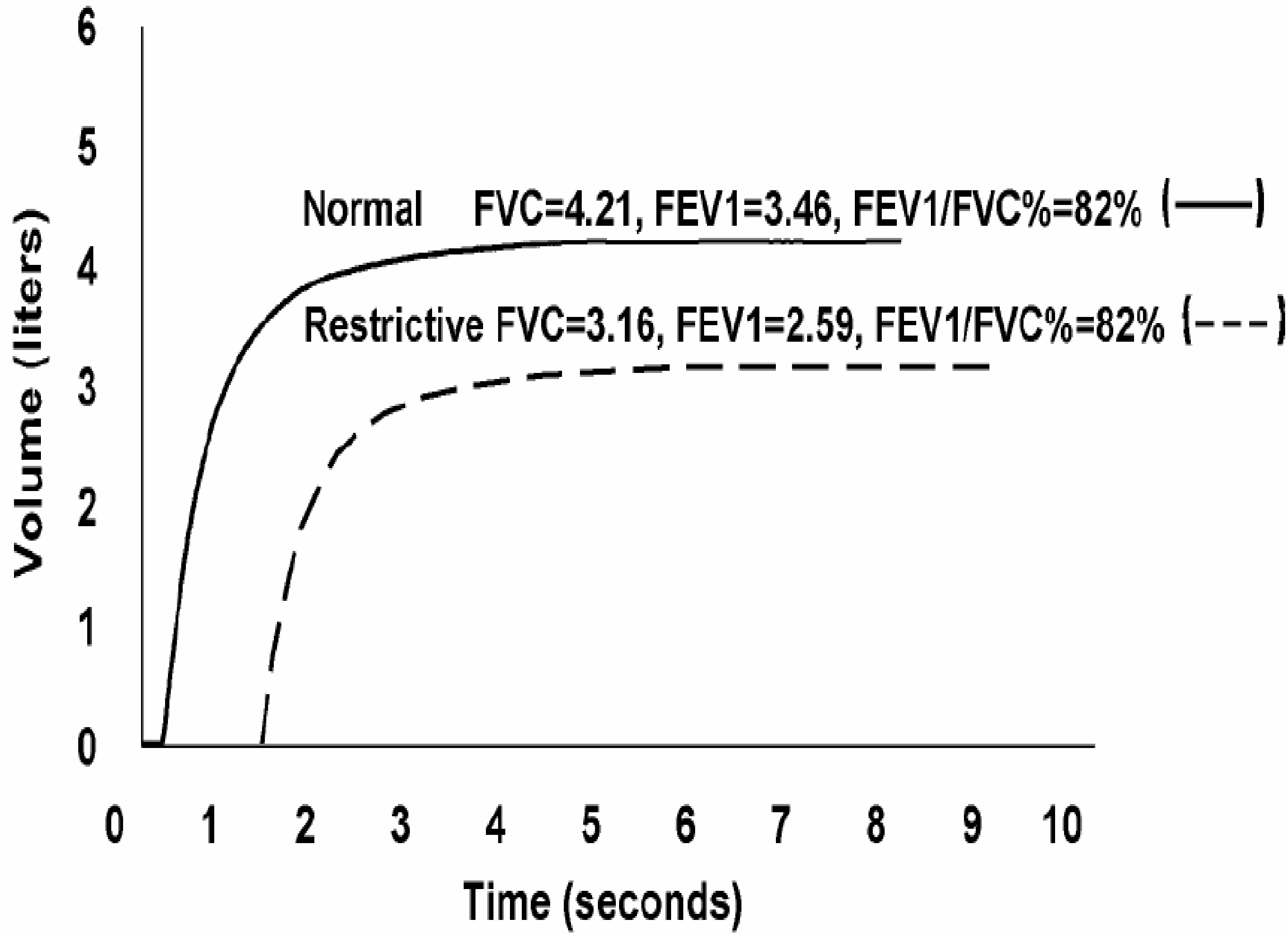
FVC = 3.89
FEV1 = 3.44
FEV1
FVC
Note: Tracing begins at 0.2 seconds, hence FEV1 is measured at 1.2 seconds
Volume (liters)
0
1
2
3
4
5
6
Time (seconds)
0
1
2
3
4
5
6
7
8
9
10



Normal FVC=3.11, FEV1=2.76, FEV1/FVC%=88.6% (——)
Obstructive FVC=2.93, FEV1=1.67, FEV1/FVC%=56.9% (- - -)
Volume (liters)
0
1
2
3
4
5
6
0 1 2 3 4 5 6 7 8 9 10
Time (seconds)

Obstructive Disorders

- Characterized by a limitation of expiratory airflow
  - Examples: asthma, COPD
- Decreased: FEV_1, $FEF_{25\text{-}75}$, FEV_1/FVC ratio (<0.7)
- Normal or decreased: FVC

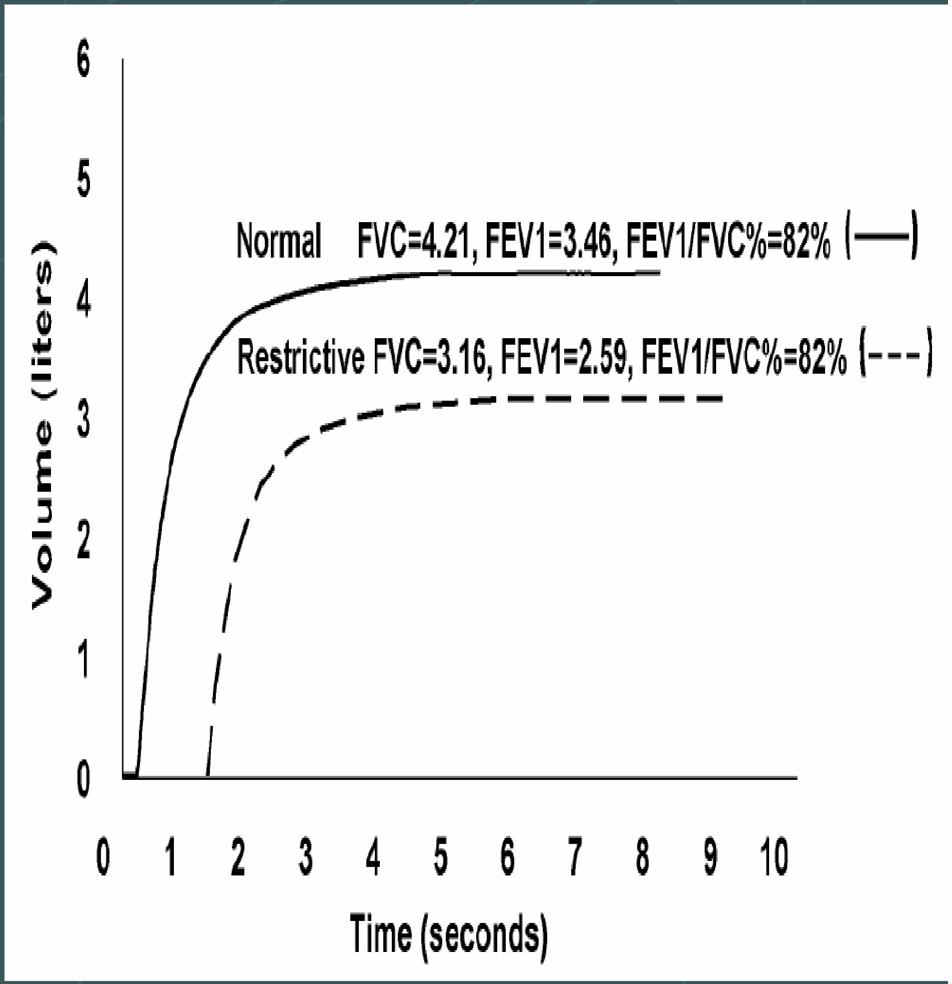

Volume (liters)
6
5
4
3
2
1
0
Normal FVC=4.21, FEV1=3.46, FEV1/FVC%=82% (——)
Restrictive FVC=3.16, FEV1=2.59, FEV1/FVC%=82% (- - -)
0 1 2 3 4 5 6 7 8 9 10
Time (seconds)

Restrictive Lung Disease

- Characterized by diminished lung volume due to:
  - change in alteration in lung parenchyma (interstitial lung disease)
  - disease of pleura, chest wall (e.g. scoliosis), or neuromuscular apparatus (e.g. muscular dystrophy)
- Decreased FVC
- Normal or decreased FEV1
- Normal or increased: FEV_1/FVC ratio

- Full expansion of the lung is limited and therefore the FVC is reduced
- FEV1 may be reduced because the stiffness of fibrotic lungs increases the expiratory pressure
- FEV1/FVC will be Normal or Increased

*if you suspect restrictive pattern you must check TLC



Identifying abnormalities

Spirometry indicates the presence of an abnormality if any of the following are recorded:

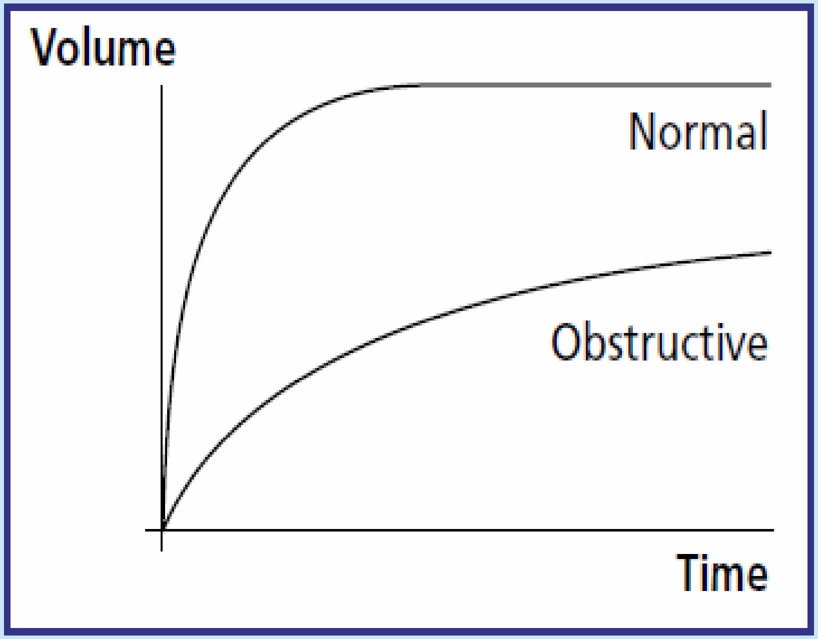
- FEV_1 <80% predicted normal
- FVC <80% predicted normal
- FEV_1/FVC ratio <0.7

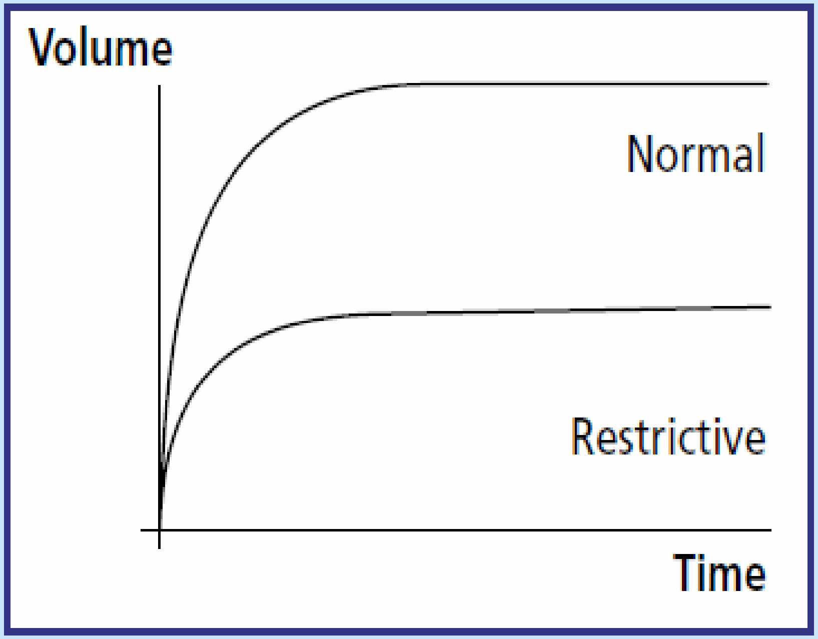
Obstructive disorder:

- FEV_1 reduced (<80% predicted normal)
- FVC is usually reduced but to a lesser extent than FEV_1
- FEV_1/FVC ratio reduced (<0.7)

Restrictive disorder:

- FEV_1 reduced (<80% predicted normal)
- FVC reduced (<80% predicted normal)
- FEV_1/FVC ratio normal (>0.7)

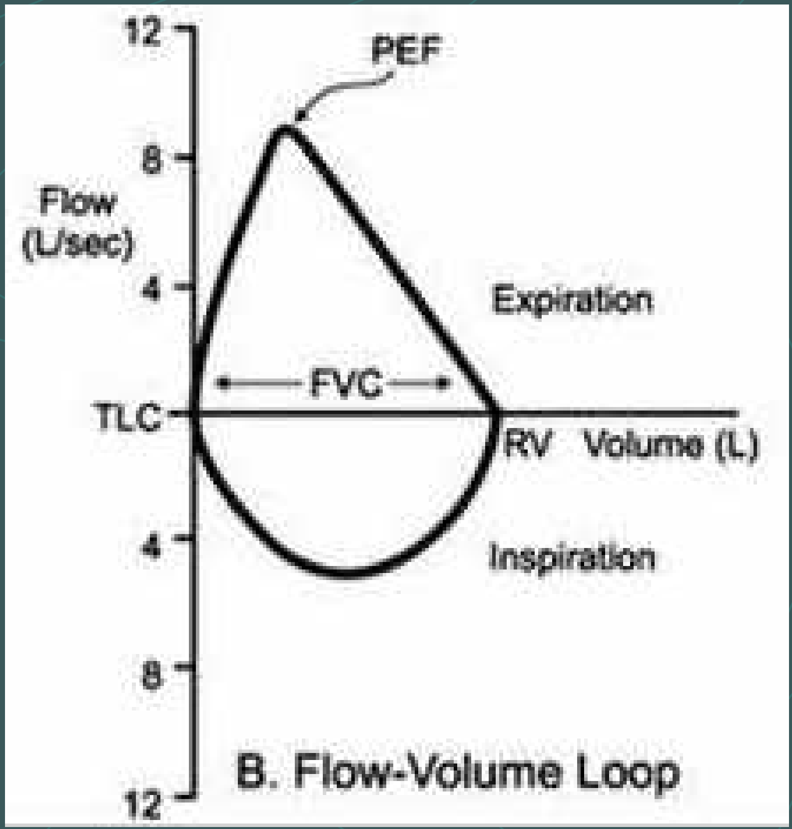


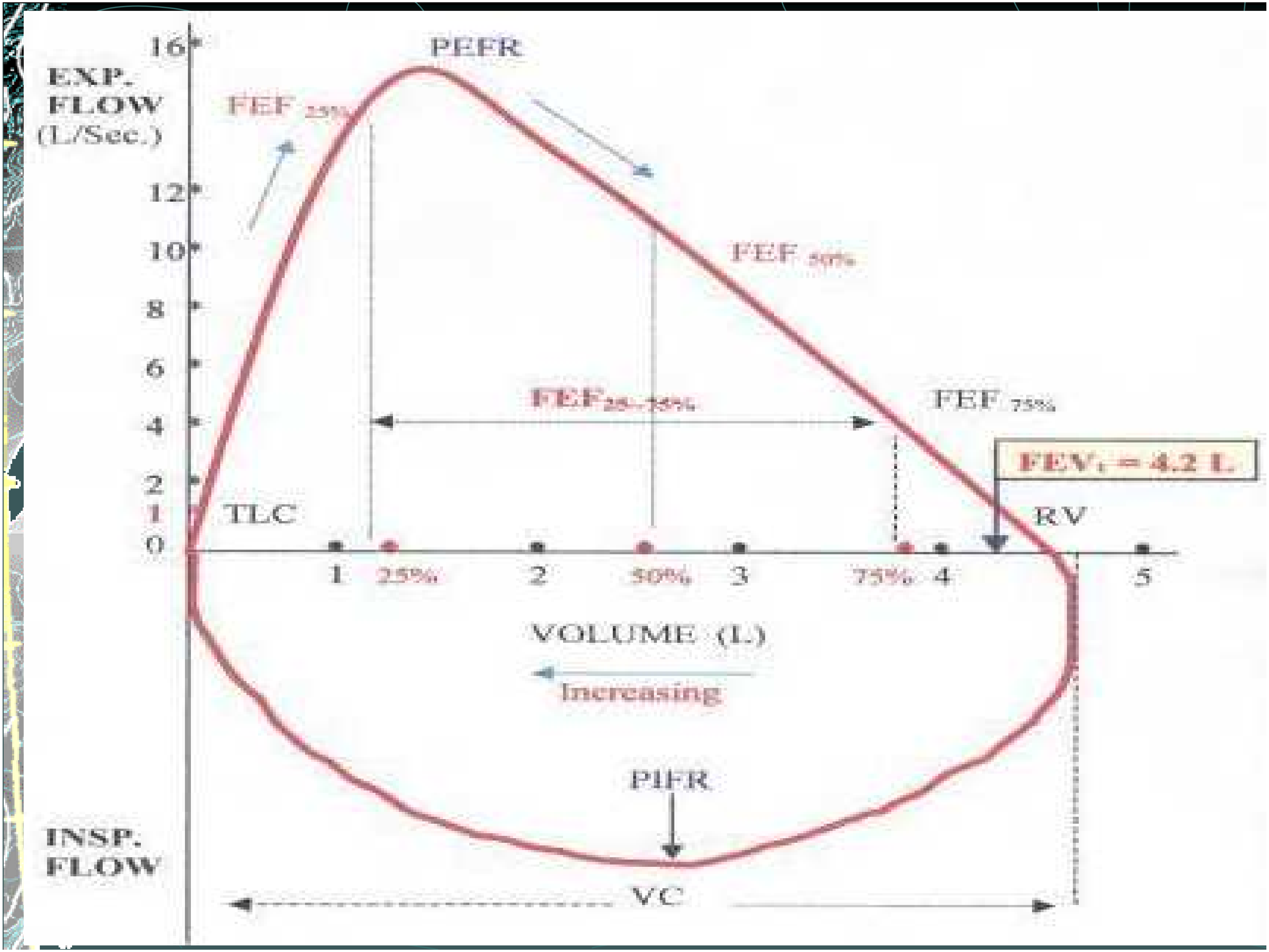


Flow-volume loops

Flow-volume loops

- Is a plot of inspiratory and expiratory flow in the vertical axis against volume in the horizontal axis, during the performance of maximally forced inspiratory and expiratory maneuvers.





EXP.
FLOW
(L/Sec.)
16
12
10
8
6
4
2
1
0
PEFR
FEF 25%
FEF 50%
FEF 25-75%
FEF 75%
FEV1 = 4.2 L
TLC
RV
1
25%
2
50%
3
75%
4
5
VOLUME (L)
Increasing
PIFR
INSP.
FLOW
VC

- Flow volume curves involve the following four phases of breathing into a spirometer

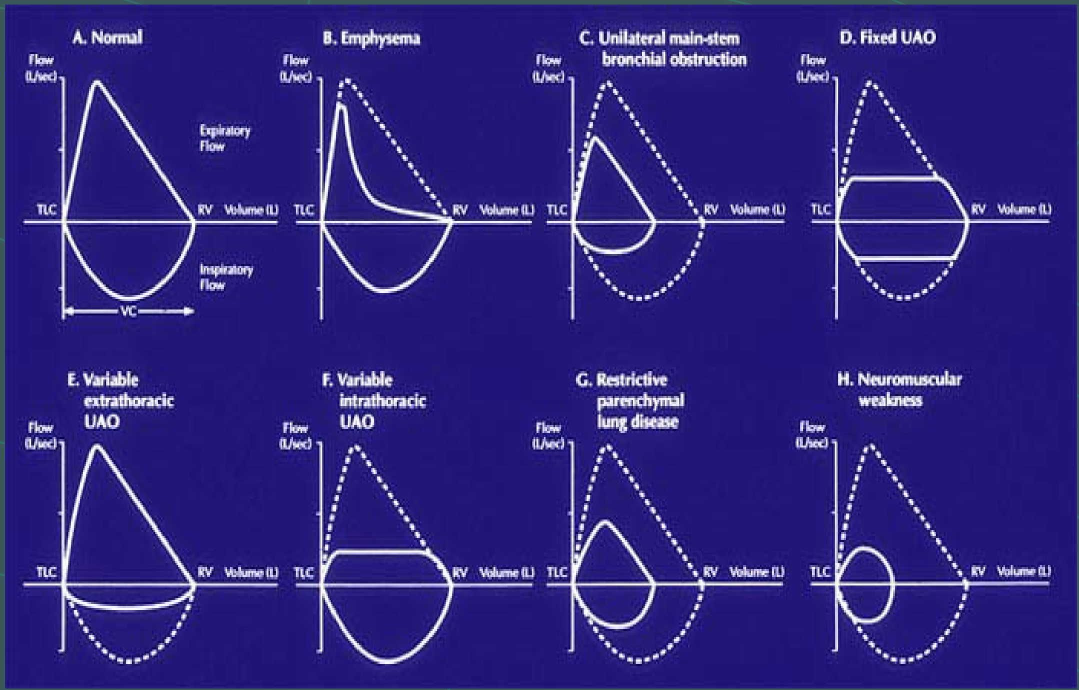
i) tidal breathing for several breaths

ii) maximal inspiratory effort to total lung capacity (TLC)

iii) maximal expiration to residual volume done as forcefully and as quickly as possible

iv) maximal inspiratory effort to TLC

- The contour of the loop assists in the diagnosis and localization of airway obstruction as different lung disorders produce distinct ,easily recognized pattern.

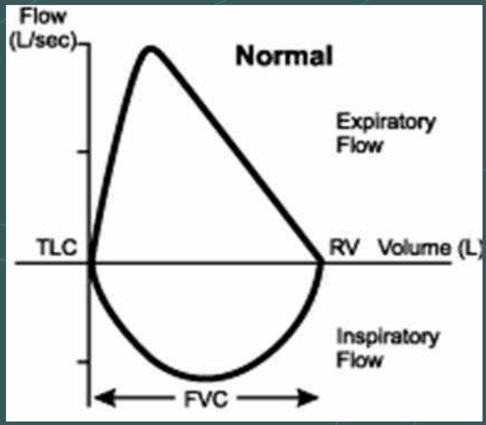


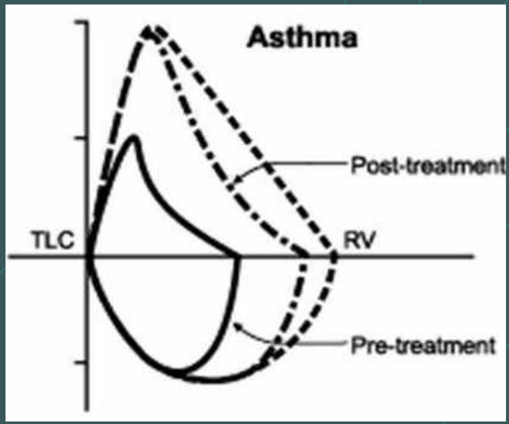
Flow volume loop in

Obstructive lung disease

Asthma

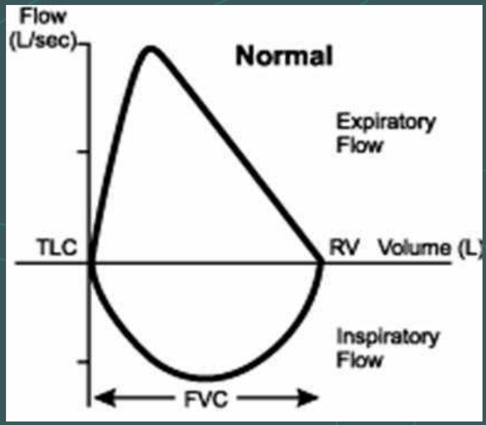
- Peak expiratory flow reduced so maximum height of the loop is reduced
- Airflow reduces rapidly with the reduction in the lung volumes because the airways narrow and the loop become concave
- Concavity may be the indicator of airflow obstruction and may present before the change in FEV1 or FEV1/FVC

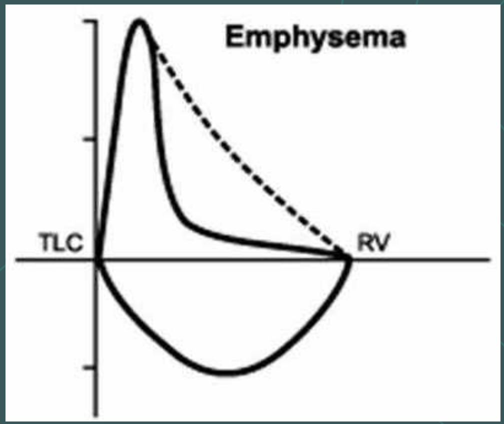




Emphysema

Airways may collapse during forced expiration because of destruction of the supporting lung tissue causing very reduced flow at low lung volume and a characteristic (dog-leg) appearance to the flow volume curve



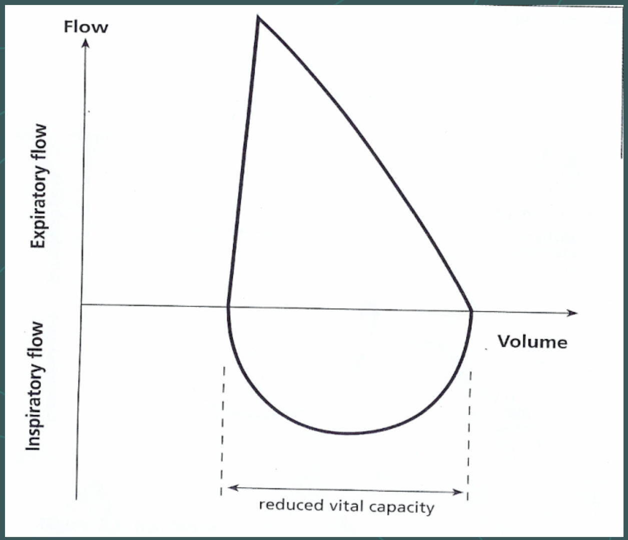


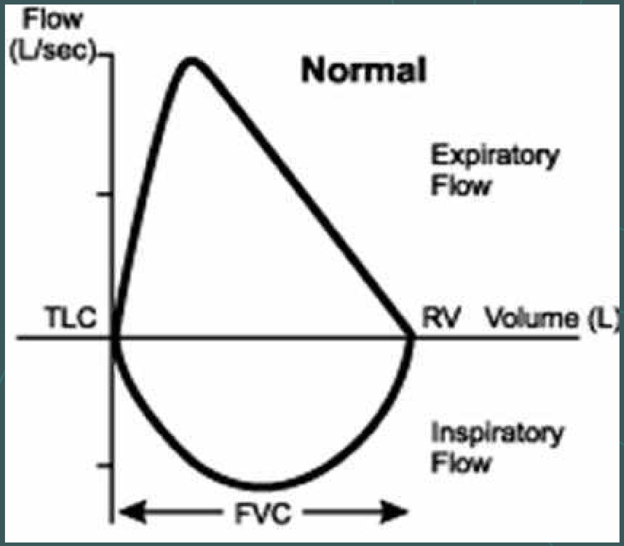
Flow volume loop in

Restrictive lung disease

Flow volume loop in Restrictive lung disease:

- Full lung expansion is prevented by fibrotic tissue in the lung parenchyma and the FVC is reduced .





- Both FEV1 and FVC may be reduced because the lungs are small and stiff ,but the peak expiratory flow may be preserved or even higher than predicted leads to tall, narrow and steep flow volume loop in expiratory phase.

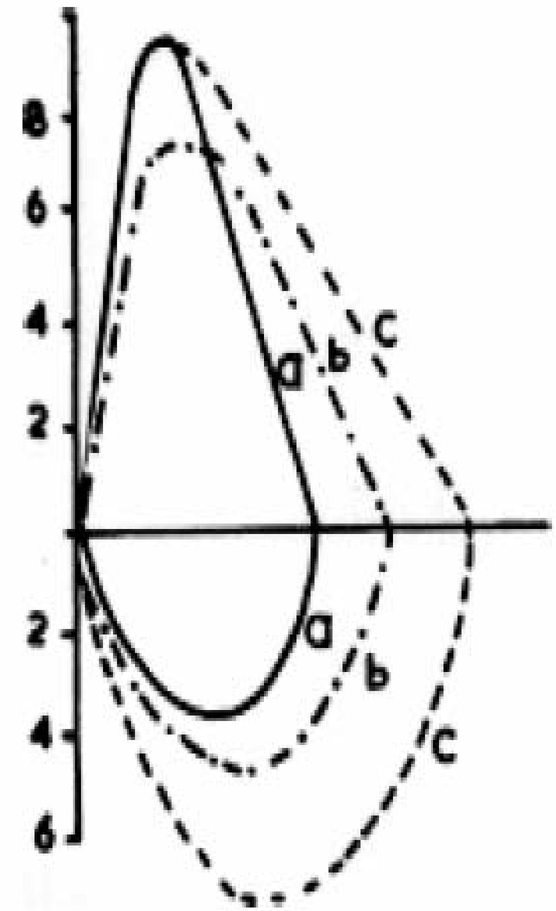
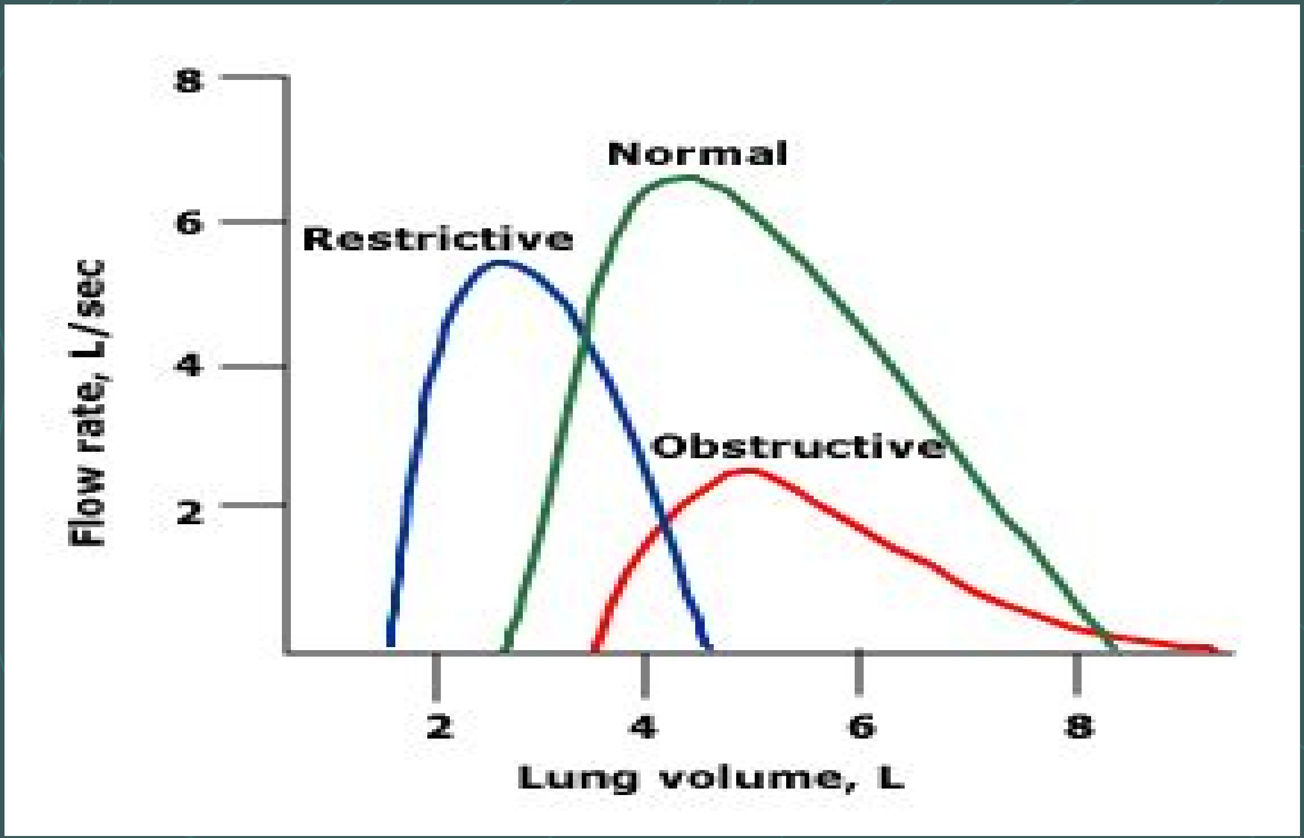


Fig. 4 : Flow volume curve in restrictive airways disease a : early stage of restrictive type, b : late stage of restrictive type, c: normal curve

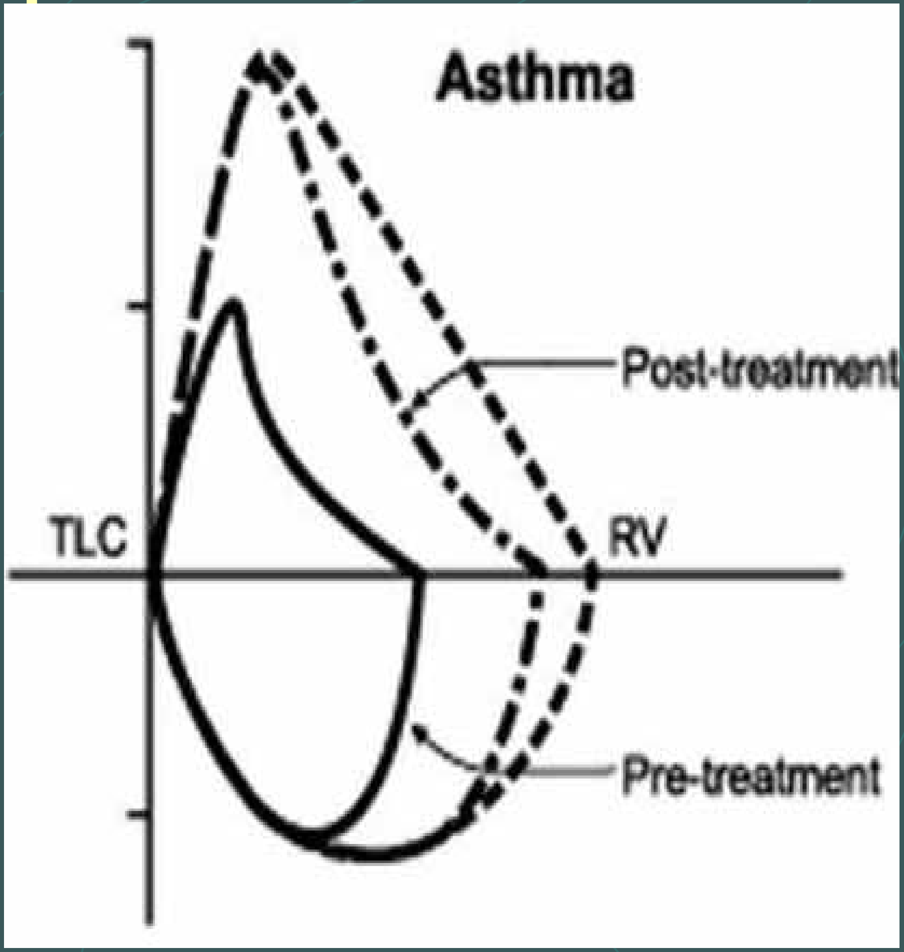
Spirometry Patterns



Bronchodilator Response

- Degree to which FEV_1 improves with inhaled bronchodilator
- Documents *reversible* airflow obstruction
- Significant response if:

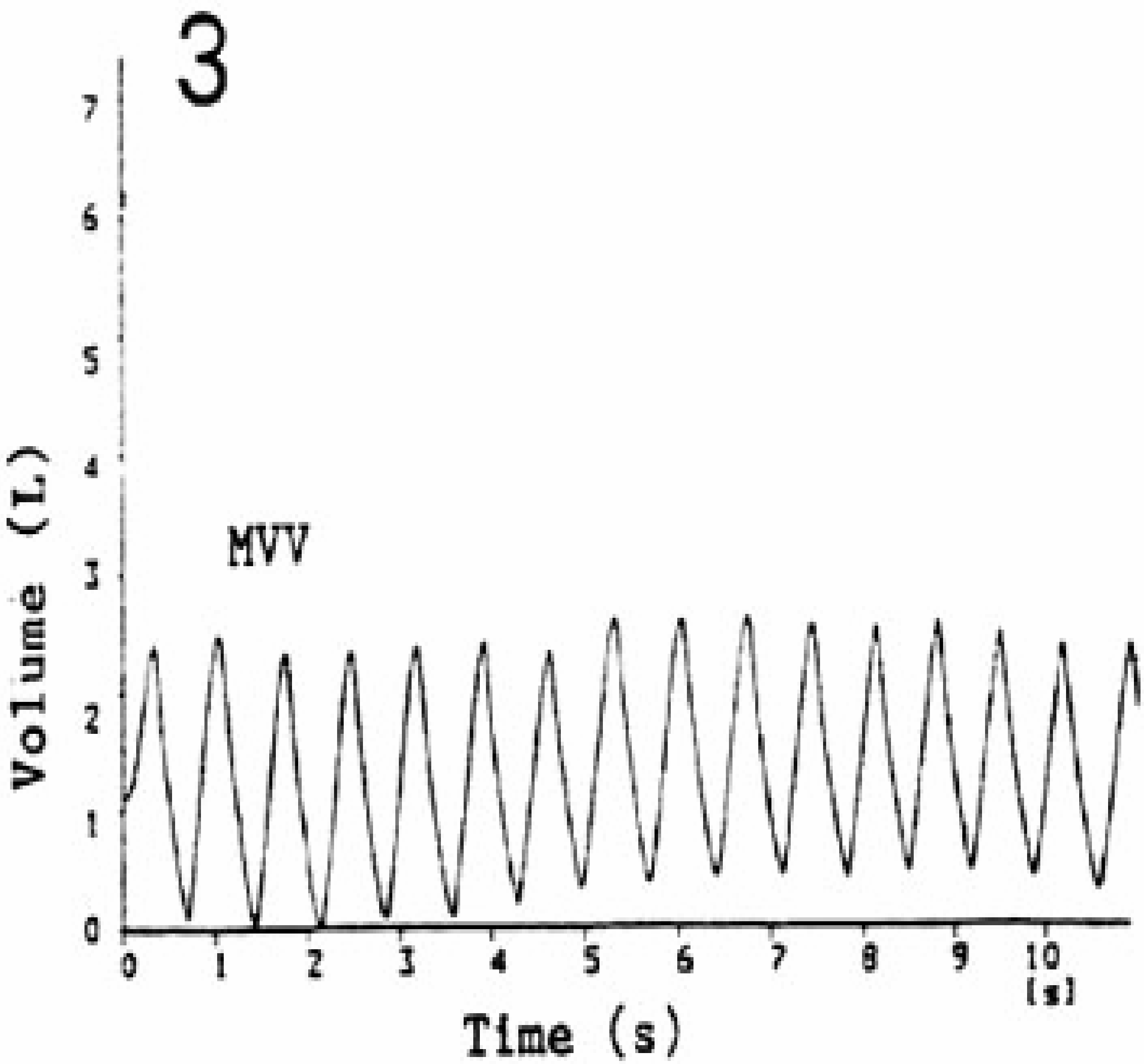
  - FEV_1 increases by 12% <u>and</u> >200ml
- Request if obstructive pattern on spirometry



Maximal Voluntary Ventilation

- This is the amount of air that can be moved in and out as fast as you can in one minute.
- We ask the patient to breath as deep and as fast as possible for 12 seconds and express it for a minute.
  We take the best of 3 measurements.
- A low MVV can occur in obstructive disease but is more common in restrictive conditions.

Note:
Rate
Volume of breaths



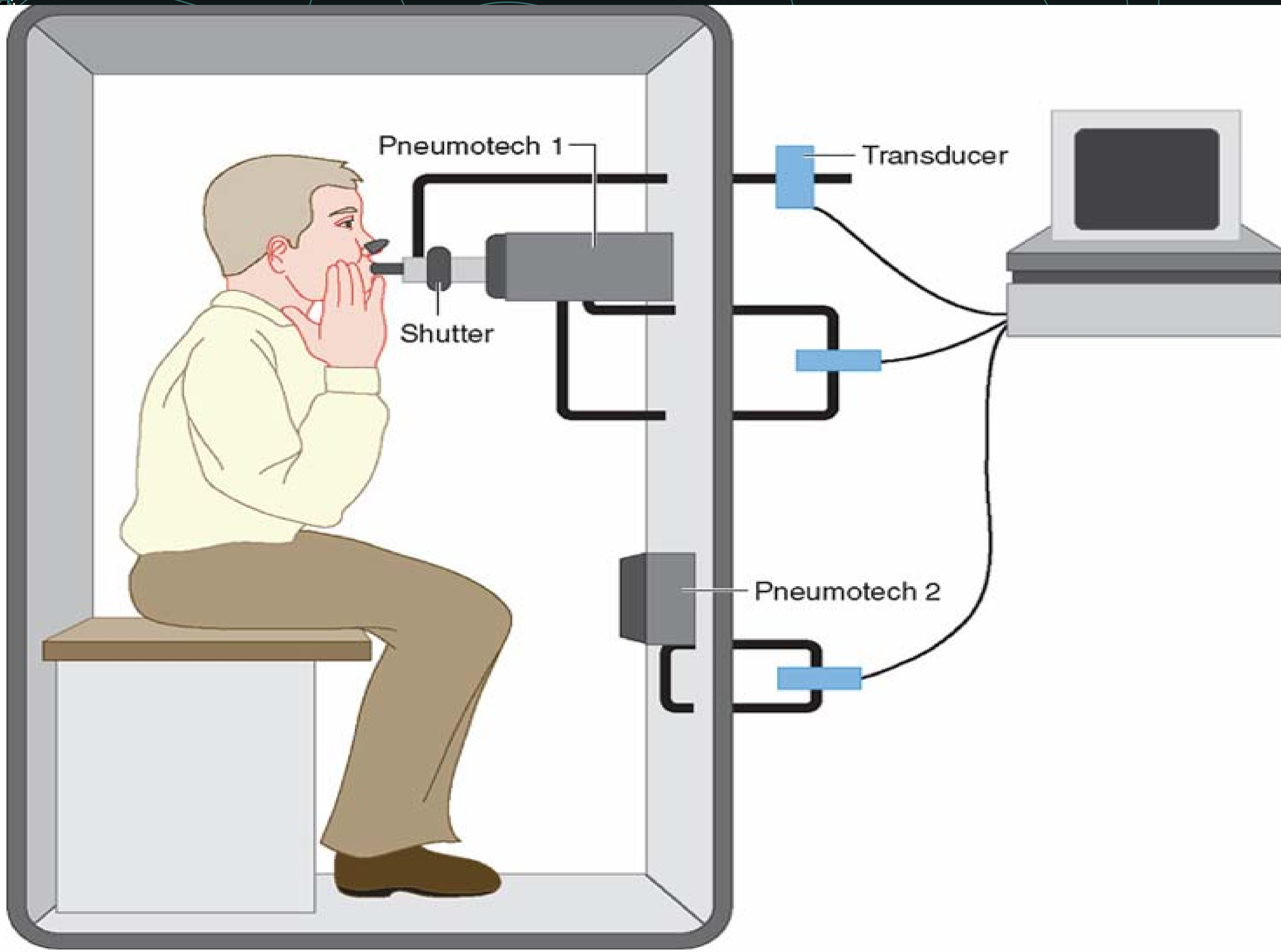
Lung Volumes

- Measurement:
  - helium
  - nitrogen washout
  - body plethsmography

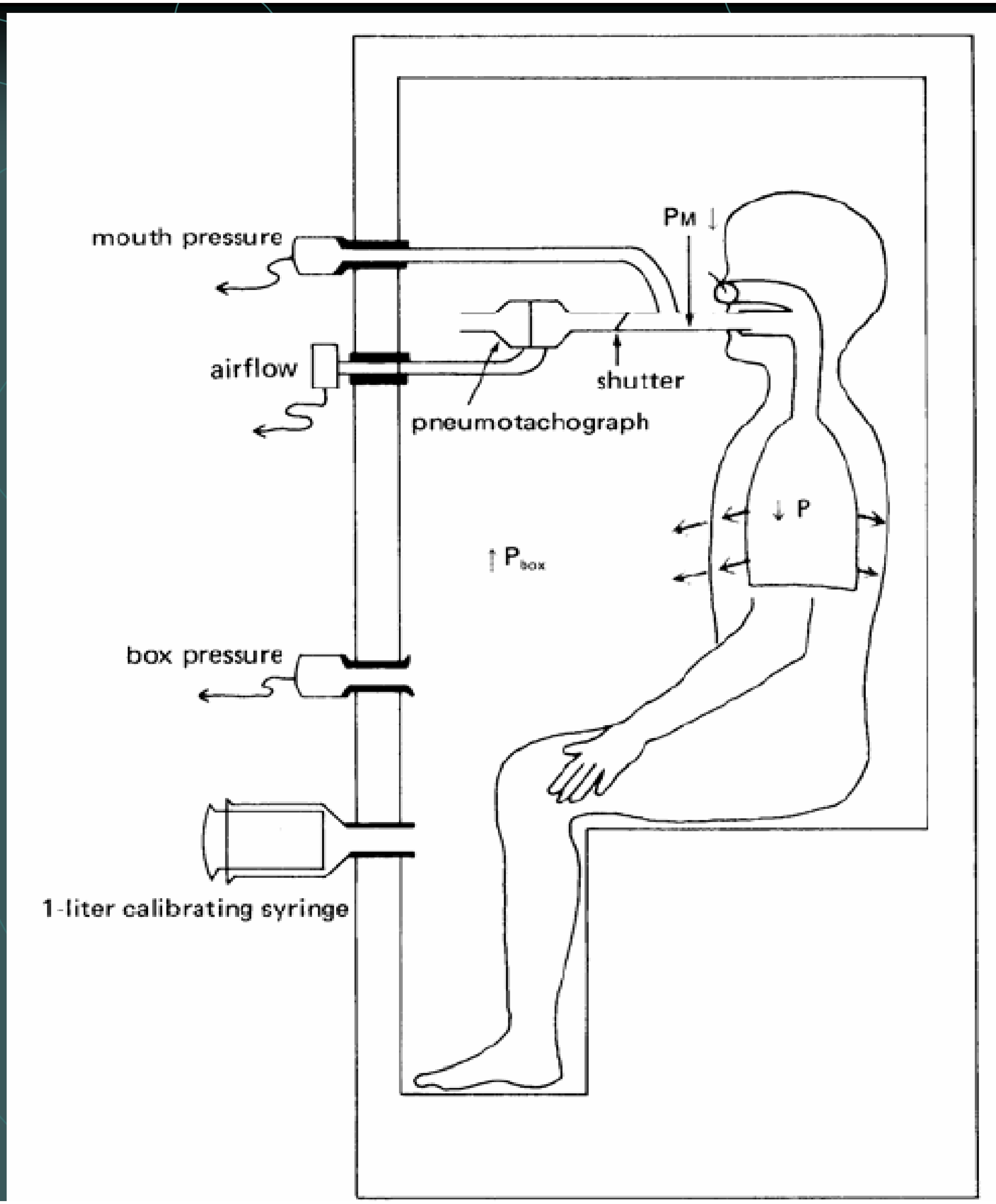
- Indications:
  - Diagnose restrictive component

Body Plethysmography

- the test is done by enclosing the subject in an airtight chamber often referred to as a body box; a pneumotachometer is used to measure airflow while a mouth pressure transducer with a shutter measures the alveolar pressure



Pneumotech 1
Transducer
Shutter
Pneumotech 2


mouth pressure
airflow
PM ↓
shutter
pneumotachograph
↓ P
↑ Pbox
box pressure
1-liter calibrating syringe

- A patient is placed in a sitting position in a closed body box with a known volume. From the FRC, the patient pants with an open glottis against a closed shutter to produce changes in the box pressure proportionate to the volume of air in the chest. The volume measured by this technique is referred to as *thoracic gas volume* (TGV) and represents the lung volume at which the shutter was closed, typically FRC.

- After the FRC is measured by any of these techniques, measurement of lung subdivisions (inspiratory capacity, expiratory reserve volume, vital capacity) ensues, ideally while the patient is still on the mouthpiece. From these volumes and capacities, the residual volume and total lung capacity can be calculated.

- most common measurements made using body plethysmographs are thoracic gas volume (VTG) and airway resistance (R_{AW})

- The relationship between alveolar and box pressure measured during respiratory efforts against a closed shutter is extended to dynamic events during breathing to measure *Raw*, *defined* as the relationship between airflow and *PA.*

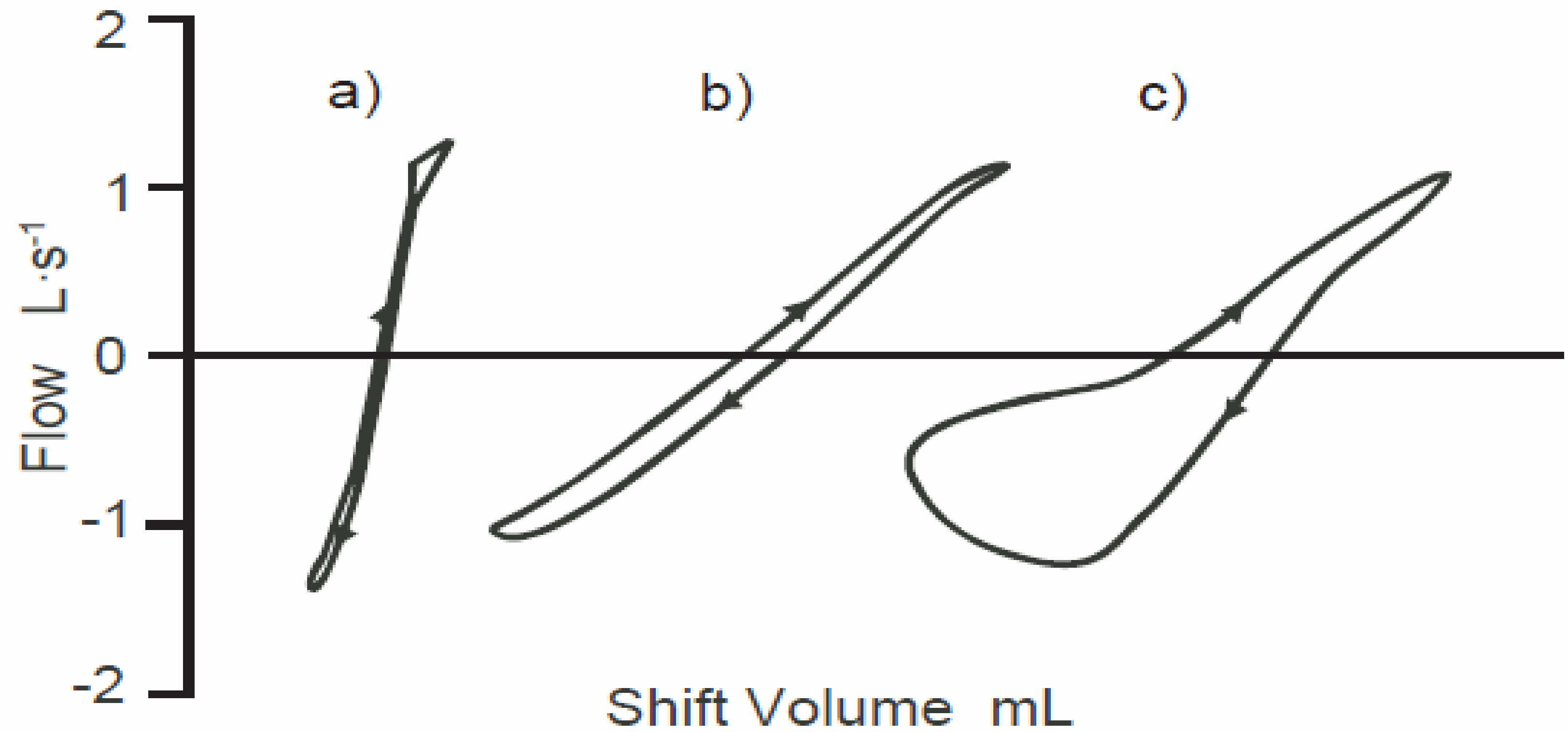


Figure 4. Specific resistance loops in a) a normal subject; b) a subject with increased large airway resistance; and c) a patient with chronic airflow obstruction.

Lung Volumes – Patterns

- Obstructive
  - TLC > 120% predicted
  - RV > 120% predicted
- Restrictive
  - TLC < 80% predicted
  - RV < 80% predicted

Diffusing Capacity

- Diffusing capacity of lungs for CO
- Measures ability of lungs to transport inhaled gas from alveoli to pulmonary capillaries
- It is a test of integrity of the alveolar-capillary surface area for gas transfer
- Depends on:
  - alveolar—capillary membrane
  - hemoglobin concentration

- a subject inhales a known volume of test gas that usually contains 10% helium, 0.3% carbon monoxide, 21% oxygen, and the remainder nitrogen. The patient inhales the test gas and holds his or her breath for 10 seconds and then is exhaled from the lung

- It is possible to calculate how much carbon monoxide was taken up during the breath hold, and what the partial pressure of carbon monoxide was during the breath hold

- DL_{CO} is calculated from the total volume of the lung, breath-hold time, and the initial and final alveolar concentrations of carbon monoxide.

Diffusing Capacity

- Decreased DLCO

  (<80% predicted)

  - Obstructive lung disease
  - Parenchymal disease
  - Pulmonary vascular disease
  - Anemia

- Increased DLCO

  (>120-140% predicted)

  - Asthma (or normal)
  - Pulmonary hemorrhage
  - Polycythemia
  - Left to right shunt

Acceptability and Reproducibility Criteria

Reproducibility Criteria

After 3 acceptable spirograms been obtained

- Are the two largest FVC within 0.2 L of each other?
- Are the two largest FEV1 within 0.2 L of each other?

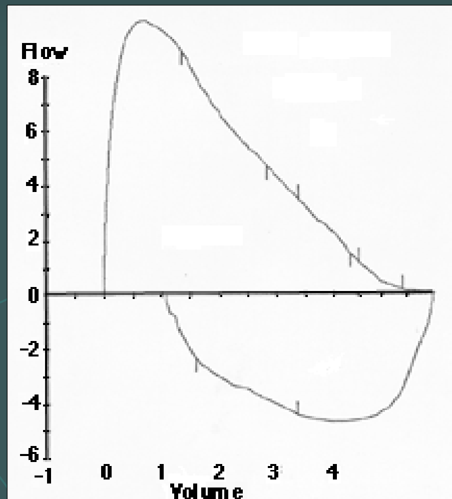
If both of these criteria are met, the test session may be concluded.

If both of these criteria are not met, continue testing until Both of the criteria are met with analysis of additional acceptable spirograms; OR a total of eight tests have been performed

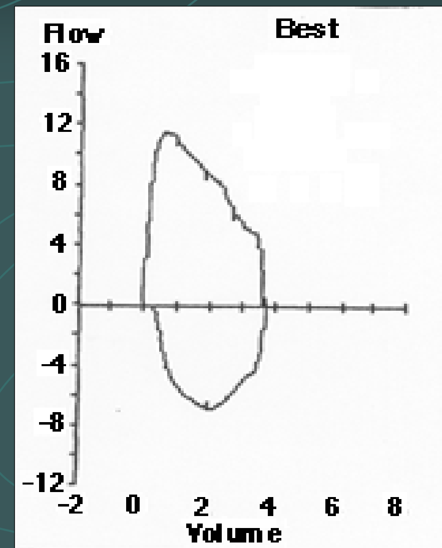
Acceptability Criteria

free from artifacts:

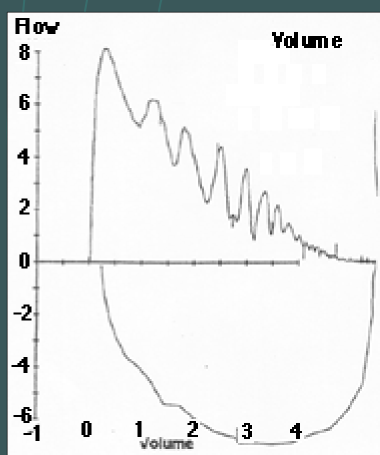
- Cough or glottis closure during the first second of exhalation
- Eary termination or cutoff
- Variable effort
- Leak
- Obstructed mouthpiece
- Have good starts
- Have a satisfactory exhalation 6 s of exhalation



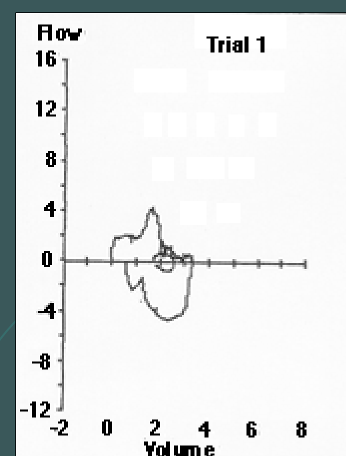
Normal



Early Glottic Closure

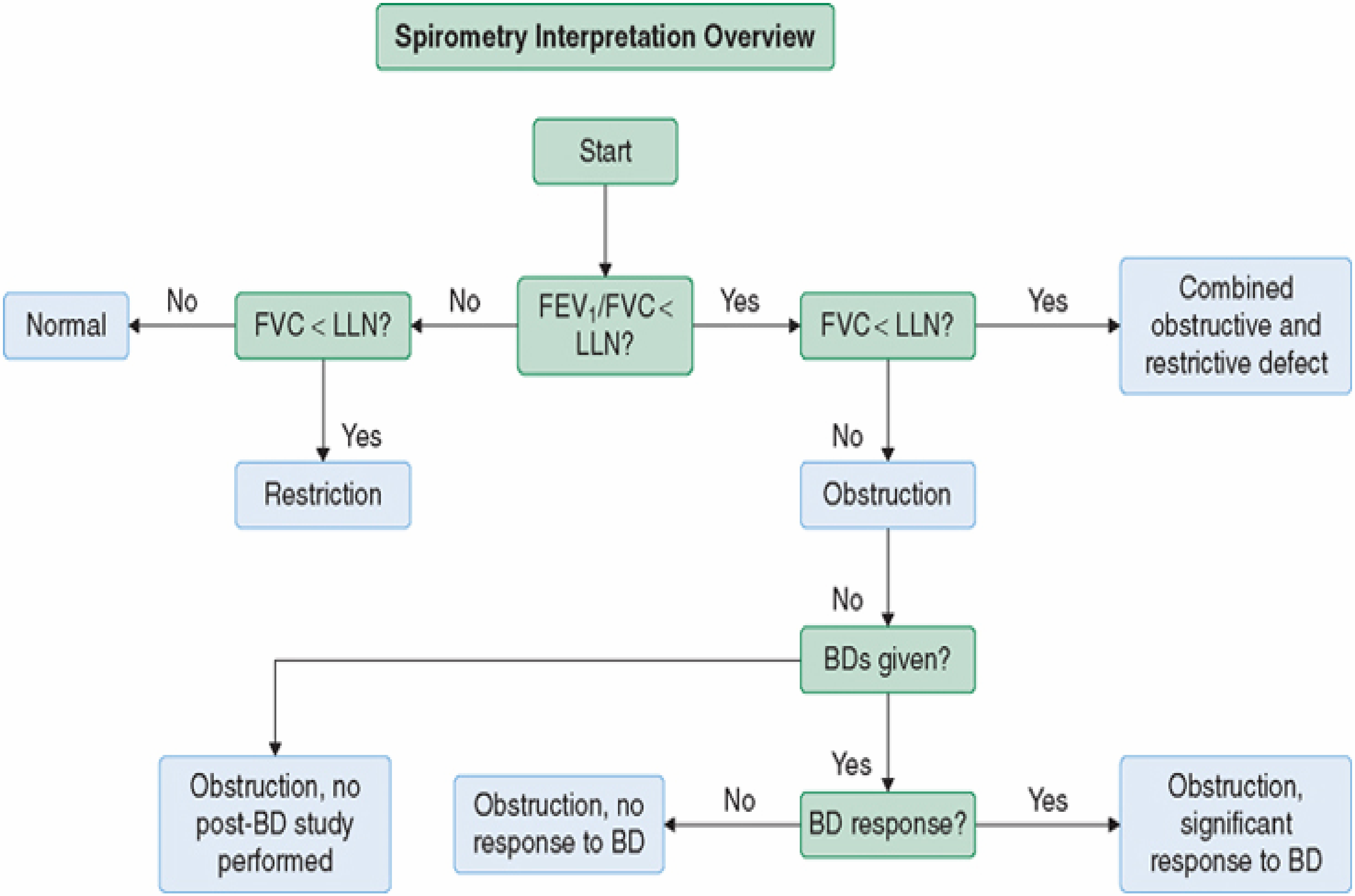


Cough



Poor Effort

INTERPRETATION of Spirometry



Algorithm for spirometry interpretation. BD, bronchodilator; FEV1, forced expiratory volume in 1 second; FVC, forced vital capacity; LLN, lower limit of normal.

CLOSE X

Calculating percentage of predicted values

Patient: 45 year old woman, height 5'3"

$$FEV_1 \quad \frac{\text{Reading } 1.43}{\text{Predicted value } 2.60} \times 100\% = 55\% \text{ of predicted normal}$$

$$FVC \quad \frac{\text{Reading } 2.5}{\text{Predicted value } 3.03} \times 100\% = 82.5\% \text{ of predicted normal}$$

$$\frac{FEV_1}{FVC} \quad \frac{\text{Reading } 1.43}{\text{Reading } 2.5} = 0.57$$

Interpretation: patient has mild airflow obstruction as FEV_1 is between 50% and 80% of predicted normal and FEV_1/FVC is <0.7.

- The observed values for the individual are expressed as percent of the predicted value (%predicted)
- It is important to note that the normal range of % predicted value for lung volumes among healthy individuals is about 100±20 % predicted.

			#7 Ref	#8 CI	#9 Pre	#10 % Ref	#11 Post	#12 % Ref	#13 %Chg
Spirometry									
#1	FVC	Liters	3.19	(2.5 - 3.9)	(2.33)	(73)	(2.30)	(72)	-1
#2	FEV1	Liters	2.62	(2.1 - 3.2)	(1.01)	(39)	(1.01)	(38)	-0
#3	FEV1/FVC	%	82	(72.6 - 90.7)	(43)		(44)		
	FEV1/SVC	%			40				
	FEF25-75%	L/sec	2.85	(1.5 - 4.2)	(0.40)	(14)	(0.38)	(13)	-6
	FEF50%	L/sec	3.50	(1.7 - 5.3)	(0.46)	(13)	(0.39)	(11)	-16
	PEF	L/sec	5.85	(3.0 - 8.7)	3.86	66	3.68	63	-5
	FET100%	Sec			9.61		11.08		15
	FIF50%	L/sec	5.50		2.14	39	2.68	49	26
	FEF/FIF50				0.22		0.14		-33
	FVL ECode				000010		000010		
Lung Volumes									
#4	TLC	Liters	4.90	(3.8 - 6.0)	(5.99)	(122)			
	VC	Liters	3.19	(2.5 - 3.9)	2.55	80			
	IC	Liters	2.10	(1.7 - 2.5)	1.87	89			
	FRC PL	Liters	2.73	(1.7 - 3.8)	(4.12)	(151)			
	ERV	Liters	1.00		0.62	62			
#5	RV	Liters	1.74	(1.0 - 2.5)	(3.43)	(198)			
	RV/TLC	%	35	(24.2 - 46.2)	(57)				
	LVol ECode				000002				
Diffusing Capacity									
#6	DLCO	mL/mmHg/min	22.3	(15.8 - 28.8)	16.4	74			
	DL Adj	mL/mmHg/min	22.3	(15.8 - 28.8)	16.4	74			
	DLCO/VA	mL/mHg/min/L	5.33	(4.0 - 6.6)	(3.75)	(70)			
	DLCO ECode				0000				
	TLC Sb	Liters	4.90	(3.8 - 6.0)	4.37	89			

Figure 1-2. Spirometric Classification of COPD Severity Based on Post-Bronchodilator FEV_1

Stage I: Mild	$FEV_1/FVC < 0.70$ $FEV_1 \geq 80\%$ predicted
Stage II: Moderate	$FEV_1/FVC < 0.70$ $50\% \leq FEV_1 < 80\%$ predicted
Stage III: Severe	$FEV_1/FVC < 0.70$ $30\% \leq FEV_1 < 50\%$ predicted
Stage IV: Very Severe	$FEV_1/FVC < 0.70$ $FEV_1 < 30\%$ predicted or $FEV_1 < 50\%$ predicted plus chronic respiratory failure

SUMMARY

Obstructive Pattern — Evaluation

- Spirometry
  - FEV_1, FVC: decreased
  - FEV_1/FVC: decreased (<70% predicted)
- FV Loop "scooped"
- Lung Volumes
  - TLC, RV: increased
- Bronchodilator responsiveness

Restrictive Pattern – Evaluation

- Spirometry
  - FVC, FEV_1: decreased
  - FEV_1/FVC: normal or increased
- FV Loop "witch's hat"
- DLCO decreased
- Lung Volumes
  - TLC, RV: decreased
- Muscle pressures may be important

PFT Patterns

- <u>Asthma</u>
  - FEV_1/FVC normal or decreased
  - DLCO normal or increased

But PFTs may be normal → bronchoprovocation

Sample problem

Problem 1

- Gina, cook, 55 years old
- She started smoking in her mid-20s and has since smoked 30 cigarettes a day. She became aware of increasing dyspnea when her daughter and grandchildren came to visit. Breathlessness prevented Gina from keeping up during a walk with the family, and her daughter insisted that she see her doctor. She has no evidence of heart disease and no other symptoms apart from a “smoker’s cough”.

Spirometry

FEV_1 = 1.39 (56% predicted)

FVC = 2.53 (86% predicted)

FEV_1/FVC ratio = 0.55

Spirometry	Interpretation
FEV_1 = 1.39 (56% predicted)	Reduced
FVC = 2.53 (86% predicted)	Normal
FEV_1/FVC ratio = 0.55	Reduced

Problem 2

- Ronald, a retired bricklayer, 69 years old
- Ronald has had a bad chest for years. Like most of his friends, Ronald started smoking when he was in the army. For many years after leaving the army, Ronald smoked up to 40 cigarettes a day.

- Ronald has had, for some time, a productive cough and for some years has needed courses of antibiotics for winter chest infections. Recently, however, even light jobs have been
- proving too demanding. He has started to spend less and less time in the garden and in his workshop

Spirometry

FEV_1 = 0.89 (28% predicted)

FVC = 2.74 (67% predicted)

FEV_1/FVC ratio = 0.32

Spirometry	Interpretation
FEV_1 = 0.89 (28% predicted)	Reduced
FVC = 2.74 (67% predicted)	Reduced
FEV_1/FVC ratio = 0.32	Severe obstruction

Problem 3

- John, an area sales manager, 42 years old
- John has always been “chesty”. Even as a child he was considered “wheezy” and he avoided physical education lessons at school. He began smoking in his early twenties and has smoked about 10 cigarettes a day ever since. Apart from bouts of coughing and wheezing following chest infections (upper respiratory tract infections –

URTI), John has enjoyed good health over the years. In the past John has been prescribed antibiotics to treat URTI, which he had often referred to as “bronchitis” and from which he typically made a slow recovery. John blamed smoking for slowing his recovery. He recently consulted his GP because yet another cold had “gone to his chest”, and his sleep was being disturbed by cough and wheeze.

Spirometry

Baseline	FEV_1 = 3.24 (76% predicted)
	FVC = 4.82 (91% predicted)
	FEV_1/FVC ratio = 0.67
Post-bronchodilator	FEV_1 = 4.17 (+ 930 ml and 29%)

Spirometry		Interpretation
Baseline	FEV_1 = 3.24 (76% predicted)	Slightly reduced
	FVC = 4.82 (91% predicted)	Normal
	FEV_1/FVC ratio = 0.67	Slightly reduced
Post-bronchodilator	FEV_1 = 4.17 (+ 930 ml and 29%)	Significant reversibility

Problem 4

- Eddie, a retired painter and decorator, 65 years old
- Eddie has only recently begun to complain of cough and breathlessness. He started smoking as a young man. Eddie made an appointment to see his doctor because he thinks he may have developed asthma. He is otherwise fit and well, and takes no medication.

- On examination he has a few fine crackles. Although asthma was suspected, his peak flow chart is steady at 350 L/minute and he has been referred for spirometry

Spirometry

FEV_1 = 1.67 (57% predicted)

FVC = 2.07 (55% predicted)

FEV_1/FVC ratio = 0.81

Spirometry	Interpretation
FEV_1 = 1.67 (57% predicted)	Reduced
FVC = 2.07 (55% predicted)	Reduced
FEV_1/FVC ratio = 0.81	Normal

- Eddie has abnormal FEV1 and FVC readings (both well below 80% of the “predicted normal” values). However the FEV1/FVC ratio is above 70% which suggests the presence of a restrictive, rather than an obstructive, airways condition.

THANK YOU!