Interpretation of lung function test

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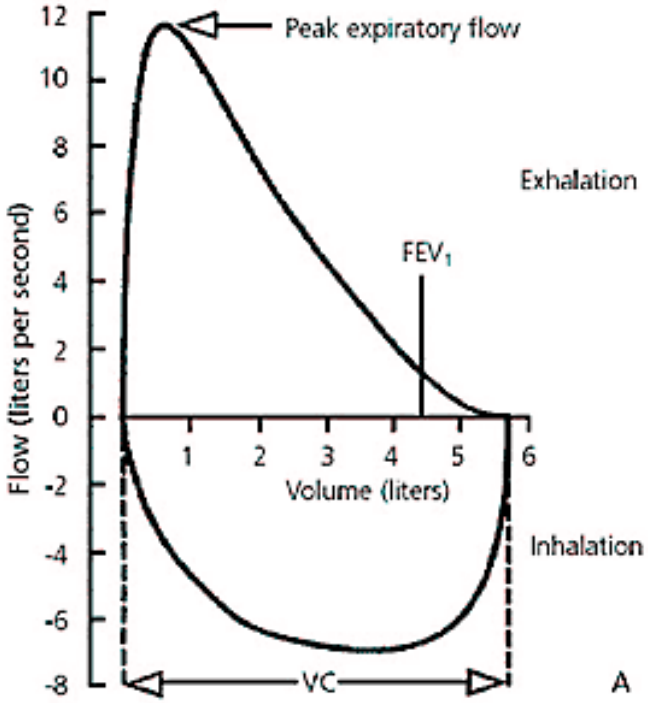
- Dynamic lung function tests?
  - What is a valid test?
  - FVC maneuver?
- Static lung function tests
  - Lung volume Vs capacity?
  - SVC maneuver?
  - Measurement methods?
- Pattern of F-V loop?
- Diffusion Capacity
- Respiratory muscle
- How to interpret ?

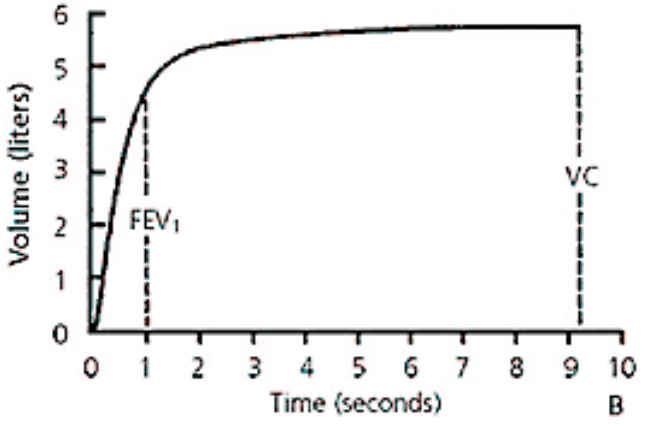
Dynamic lung function test

- FEV1- Vol. expired in first sec
- FVC
- FEF25-75%- flow over mid portion of FVC
- PEFR- Peak exp flow

- Flow-volume (FV) curve
- Volume-time (VT) curve

- Use of **FVC maneuver**





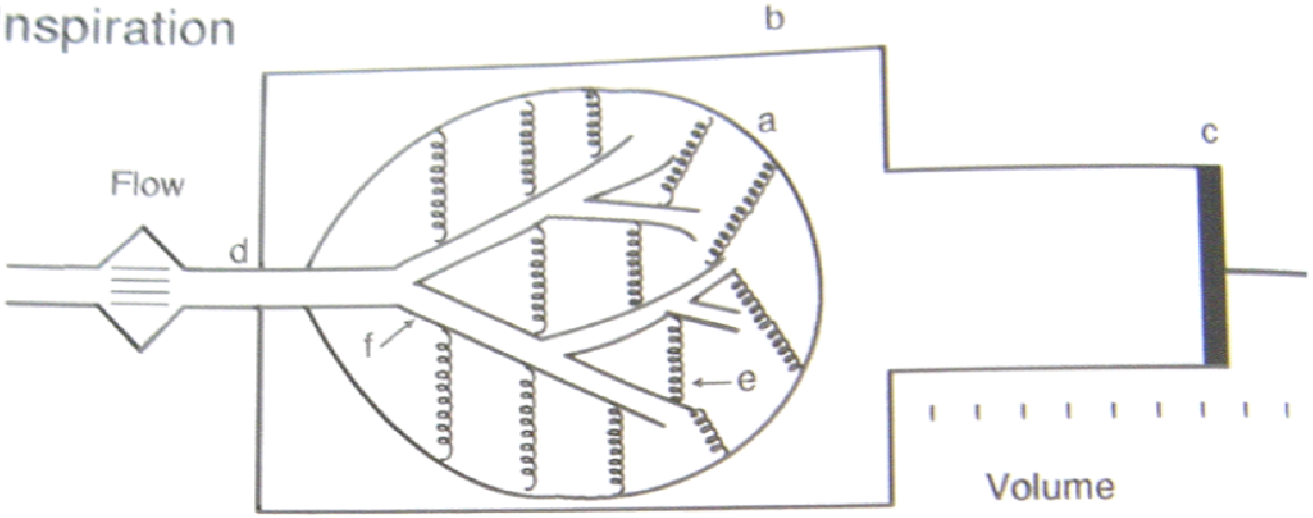
FVC maneuver

- FVC maneuver
  - expire as **forcefully and rapidly** as possible after maximal inspiration

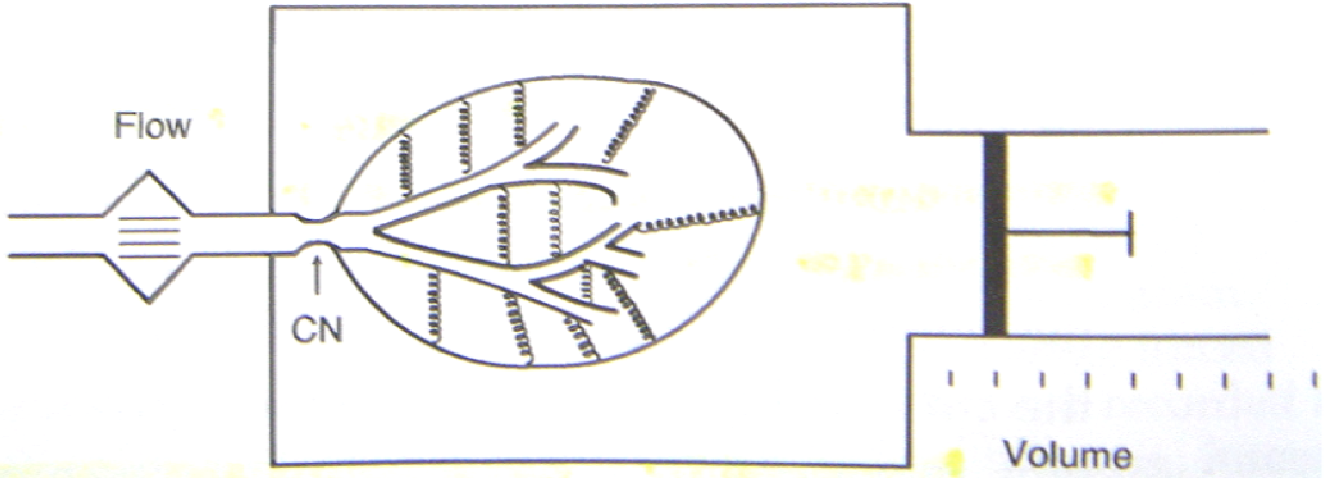
- FVC test is important because there is a **unique limit to max. exp. flow at any lung volume**
- As volume decrease, dynamic compression of airway produces a critical narrowing that develop in trachea and produce limitation of flow

- FVC maneuver make the test ***reproducible and interpretable***

A. Full Inspiration



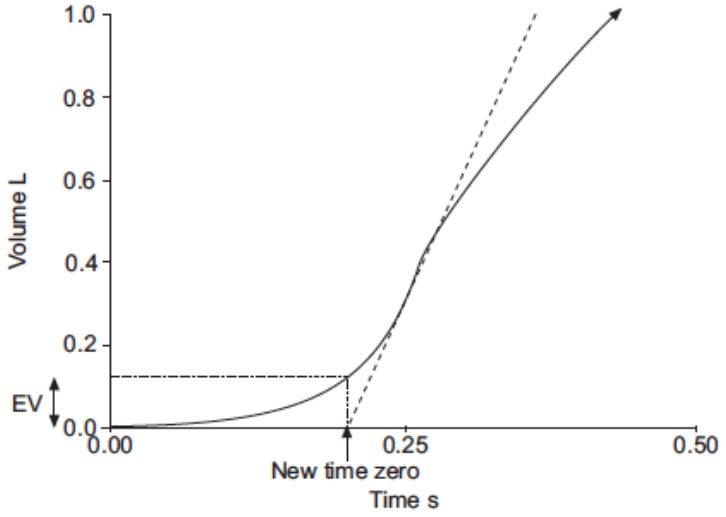
B. Forced Expiration



A Valid Test is……..

Within-manoeuvre criteria

- Individual spirograms are "acceptable" if
  - They are free from artefacts [3]
    - Cough during the first second of exhalation
    - Glottis closure that influences the measurement
    - Early termination or cut-off
    - Effort that is not maximal throughout
    - Leak
    - Obstructed mouthpiece
  - They have good starts
    - Extrapolated volume <5% of FVC or 0.15 L, whichever is greater
  - They show satisfactory exhalation
    - Duration of ⩾6 s (3 s for children) or a plateau in the volume–time curve or
    - If the subject cannot or should not continue to exhale

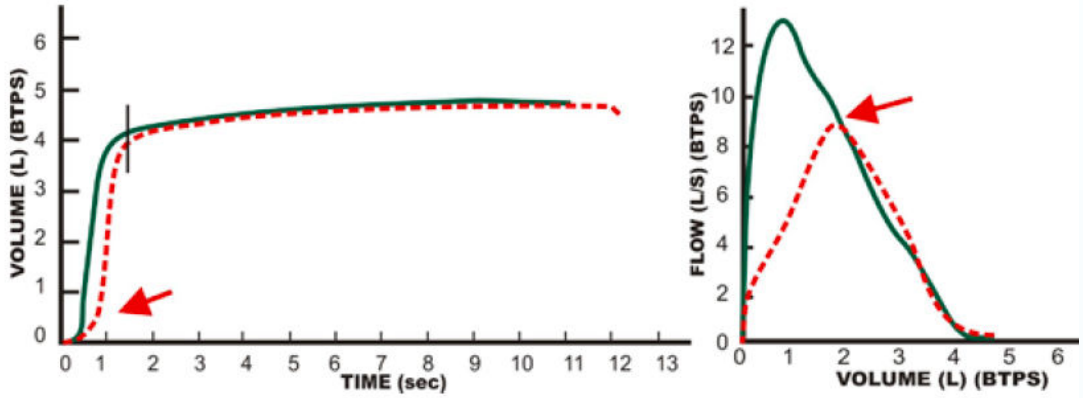


Between-manoeuvre criteria

- After three acceptable spirograms have been obtained, apply the following tests
  - The two largest values of FVC must be within 0.150 L of each other
  - The two largest values of FEV_1 must be within 0.150 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 (optional) or
  - The patient/subject cannot or should not continue
- Save, as a minimum, the three satisfactory manoeuvres

ATS guideline 2005

START of TEST



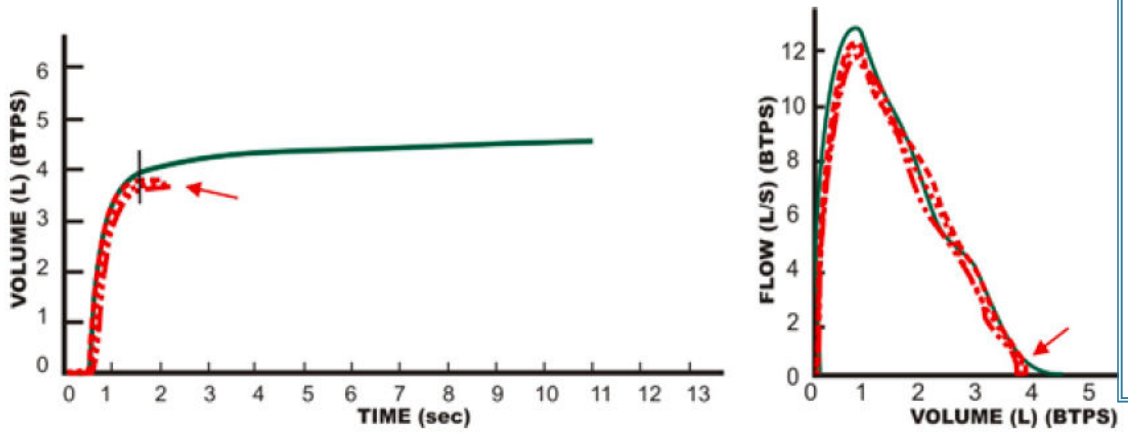
Hesitation in blowing out before initial blast

Most easily seen in F-V curve (peak flow displaced to right)

Extrapolated vol >0.15L or 5% of VC

Affect FEV1, not FVC

END of TEST



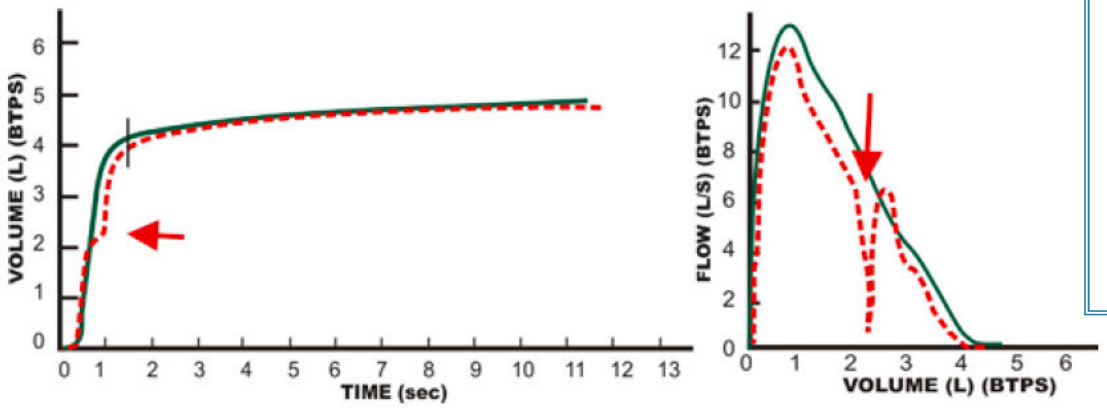
Early Termination

Lack of plateau on the VT curve

The falsely reduced FVC may be misinterpreted as indicating a “restrictive impairment.”

The falsely increased FEV1/FVC ratio may miss a true “obstructive impairment”

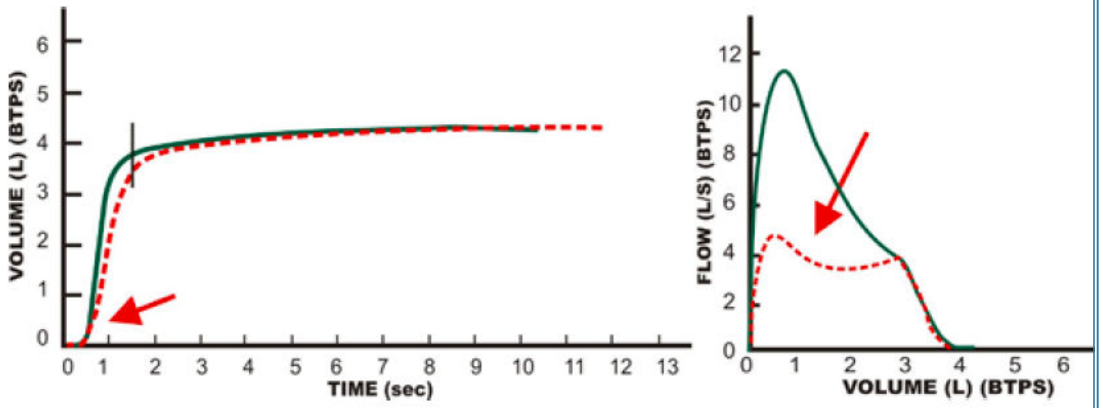
ARTIFACTS



COUGH:

Jagged interruption in the FV curve

Coughing in the first second **<u>may affect the FEV1,</u>** while coughing after the first second will not affect the FVC measurement unless the subject stops blowing prematurely

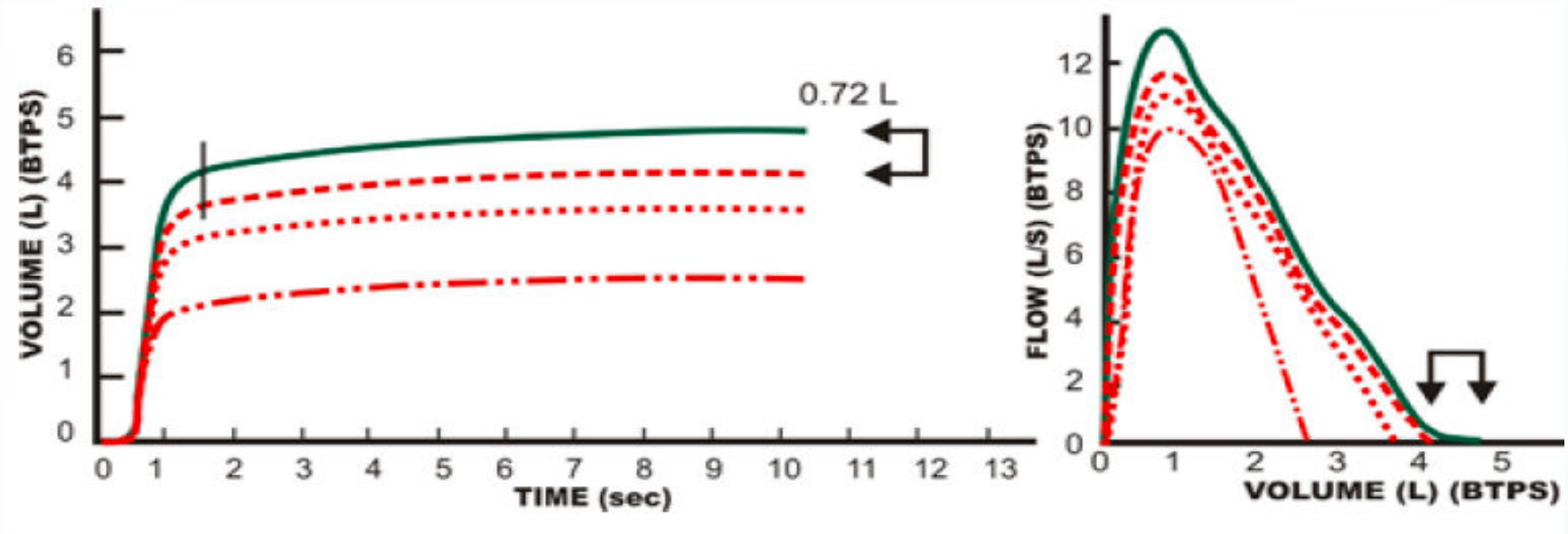


VARIABLE, NON SUSTAINED EFFORT

Often seen as a dip in FV curve

May reduce FEV1 and thus FEV1/FVC ratio

Ask the subject to blast one breath out HARD and FAST, and KEEP BLOWING out



BETWEEN MANUEVER ACCEPTIBLITY

Gap between the FVC plateaus on multiple VT curves

Similar shape but curves will vary in size.

FV curves with sharp peaks → Good initial blasts, but the difference in maximal airflow (PEF) may be caused by lower elastic recoil associated with less “stretching” of the lung with smaller volumes

Falsely reduced FVC can be misinterpreted as “restrictive impairment.”

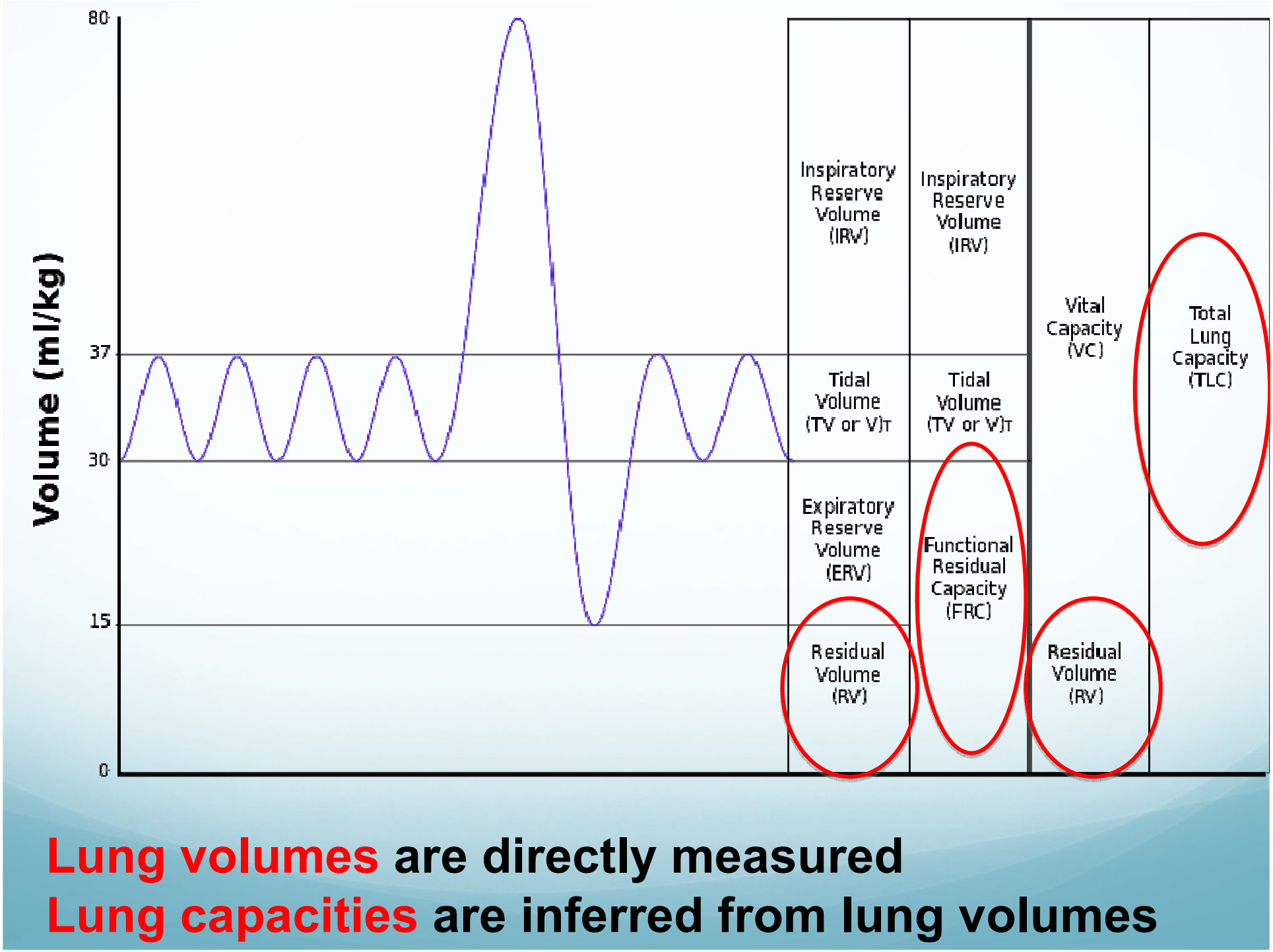
Which values should we use?

- The largest FVC and the largest FEV1 should be measured
- PEF is the largest value from an acceptable effort
- All other flows (eg FEF 25-75%) are taken from the acceptable effort with the largest sum of FVC and FEV1

Static Lung function test

- Lung volume
  - FRC
  - RV, TLC

- **Slow vital capacity (SVC)** maneuver
  - maximal amount of air exhaled **slowly and steadily** from full inspiration to maximal expiration. Not time-dependent
  - Expiratory VC (EVC) vs Inspiratory VC (IVC)
  - < FVC esp. in patients with airway obstruction



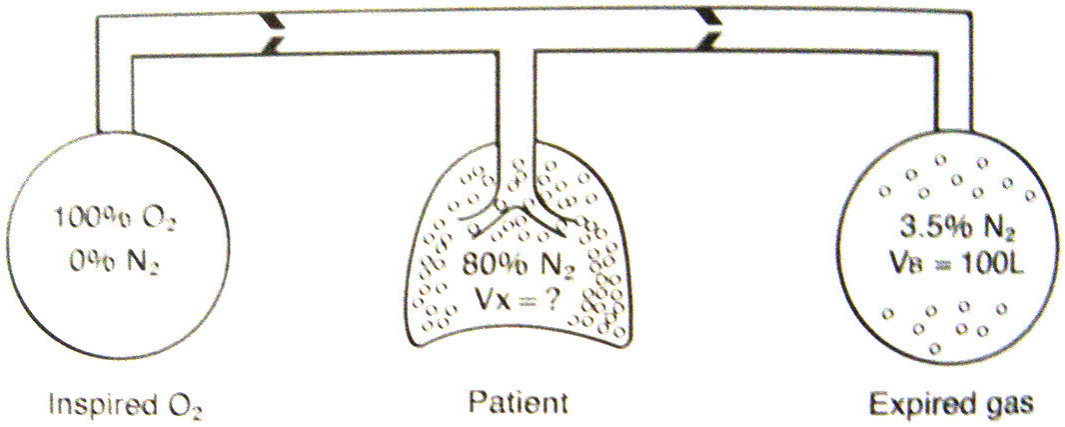
Lung volumes are directly measured

Lung capacities are inferred from lung volumes

Methods to measure FRC

- **Nitrogen washout method**
- **Helium dilution method**
- **Plethysmography (body box/ TGV)**

Nitrogen Washout test



Initial volume of N_2 in patient = 0.8 (Vx)

Vx = FRC

Final volume of N_2 in expired bag = 0.035 (V_B)

V_B = volume of bag = 0.035 (100)

There is no loss of N_2 from system

so initial N_2 volume = final N_2 volume

0.8(Vx) = (0.035)(100)

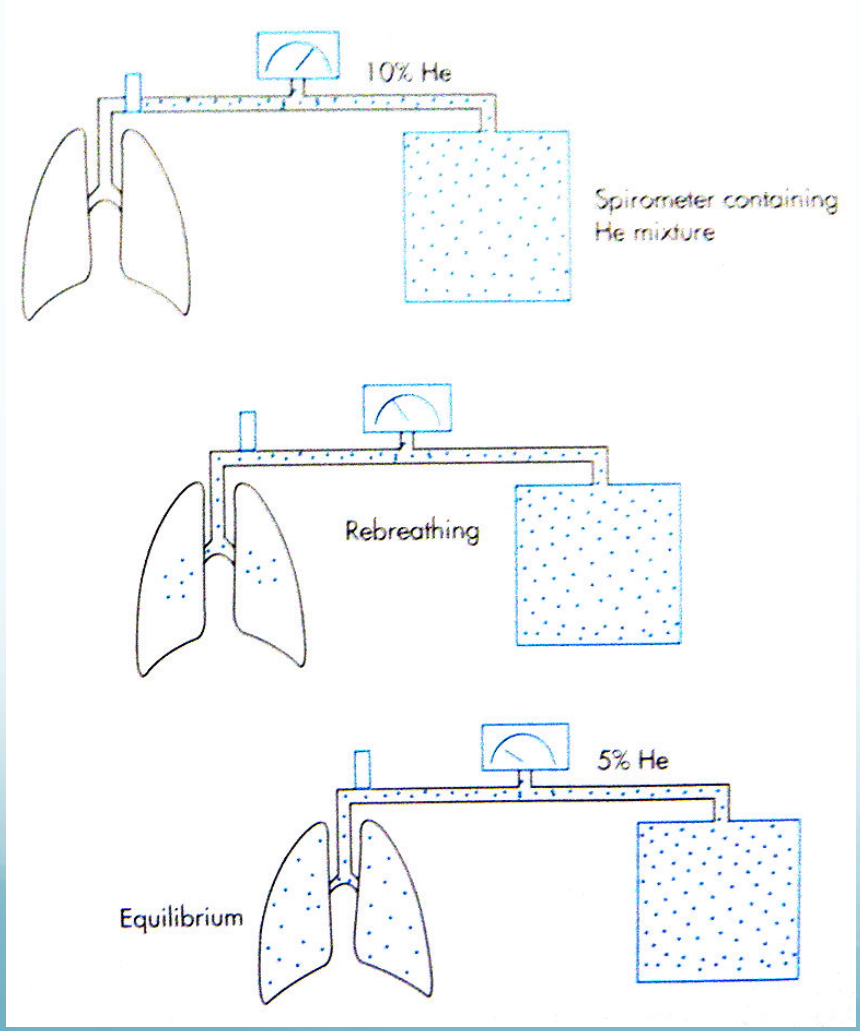
Vx = 4.37 L = FRC

Given 100% oxygen for several minutes, with nitrogen in the lung washout; exhaled to separate bag

The concentration of collected nitrogen is measured and the volume collected is measured

FRC was then calculated

Helium dilution method

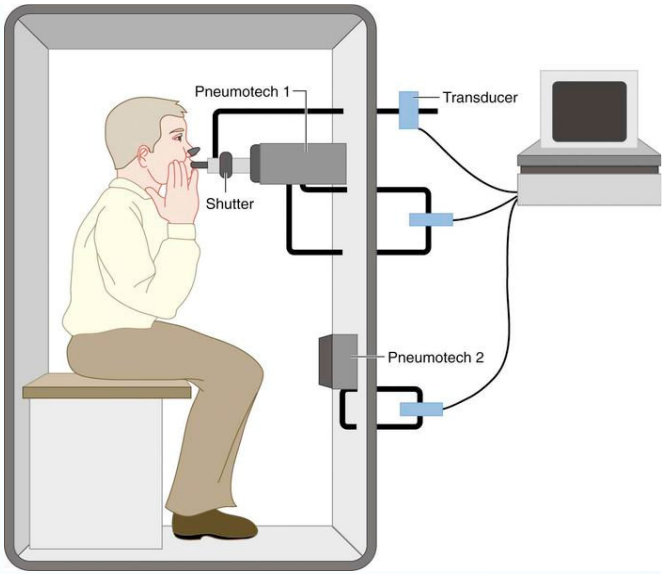


The spirometer system contain a known volume of gas (He with known conc)

The subject rebreath until the He conc reach plateau (equal conc He in lung and system)

FRC was then calculated

Plethysmography



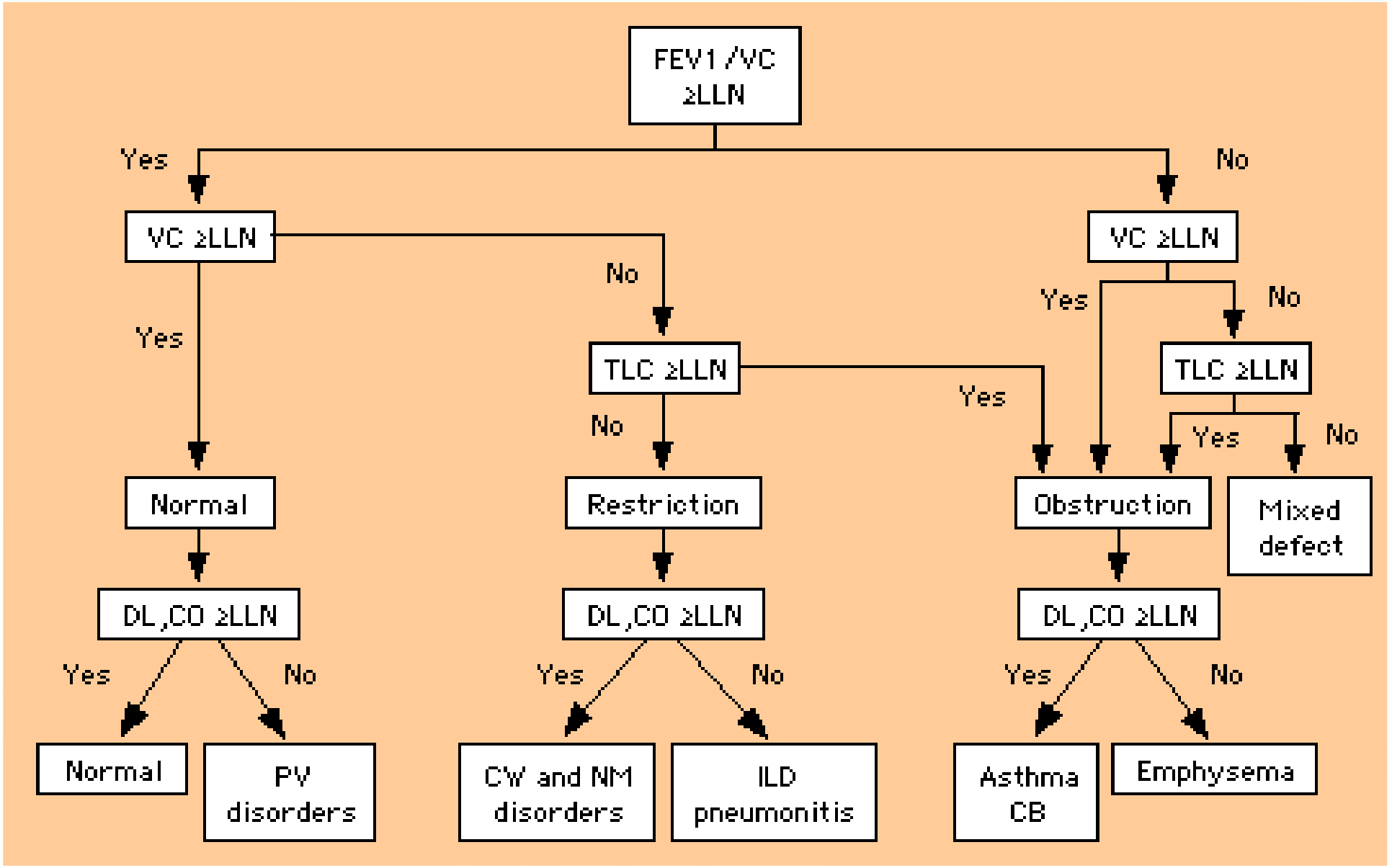
- By applying Boyles law (PV = constant)
- FRC = changes of volume / changes of pressure x (pleth pressure)
- Volume measured is also call thoracic gas volume (TGV)

- **Measurement not affected by degree of airway obstruction**
- **➔ values are usually larger then that measured by nitrogen washout or helium dilution method**

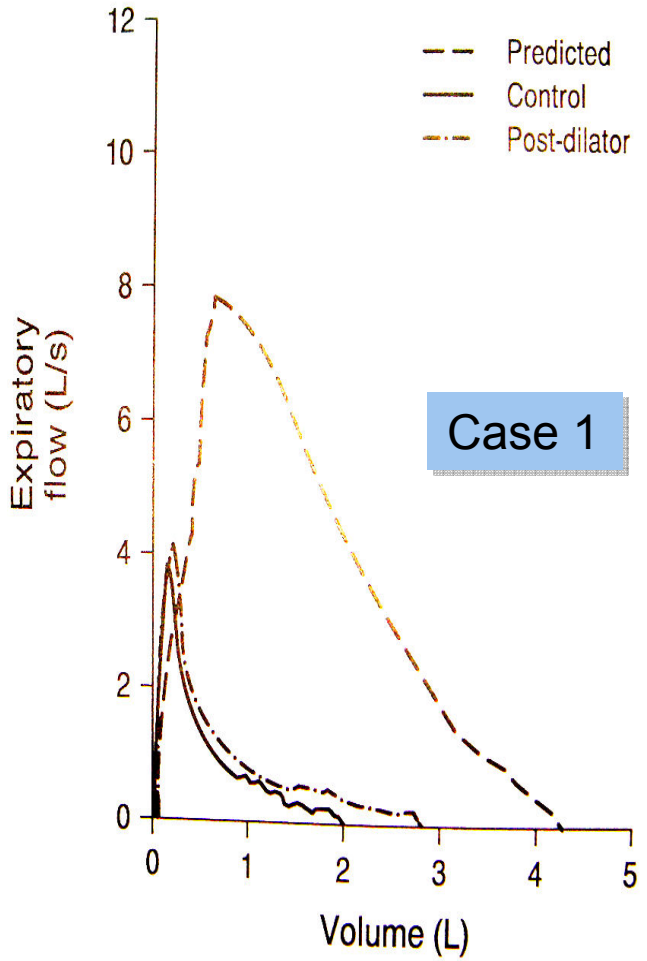
How about non communicating bulla??

- The gas trapped in the bulla cannot be measured by dilution method
- TGV could measure all air in the chest including trapped air in the bulla

Interpretation of lung function test ATS 2005



CASE 1



71/M , Chronic smoker
c/o: progressive SOB and wheezing on exertion

FVC:	1.94L (45%	predicted)
FEV1:	1.03L (31%	predicted)
FEV1/FVC:	53%	
FEF 25-75:	0.4	(15% predicted)
MVV:	51	(41% predicted)
TLC:	9.37	(142% predicted)
RV/TLC:	75	(214% predicted)
DLCO:	10	(40% predicted)

Interpretation

- Low FEV1/FVC, increased TLC, low DLCO
- Obstructive pattern with hyperinflation, low DLCO consistent with emphysema

Obstruction Pattern

Dynamic lung function parameters:

- FVC, FEV1, FEV1/FVC ratio, PEF, PFE 25-75%: decreased
- MVV decreased
- Slope of FV curve: decrease

Static Lung function test

- TLC, RV, RV/TLC ratio: increase

Diffusion:

- DLco: decrease (esp. in emphysema)
- Kco: decrease (esp. in emphysema), except in asthma

Respiratory muscle

- PEmax/PImax: not affected
- Raw: elevated

(FEV1/FVC ratio)

Fixed ratio (0.7) Vs LLN ???

- FEV1/FVC decreases with increasing age and height in normal subjects
  - Fixed cut-off will over-diagnosis of airflow obstruction in elderly and tall subjects
- ATS/ERS task force recommend the use of lower limit of normal (LLN) if prediction equations are available
- The LLN is typically the 5th percentile value

adult Chinese in Hong Kong—Chest 2006

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Original Research | February 2006

Updated Spirometric Reference Values for Adult Chinese in Hong Kong and Implications on Clinical Utilization*

FREE TO VIEW

Mary Sau-man Ip, MD, FCCP; Fanny Wai-san Ko, MBChB, FCCP; Arthur Chun-wing Lau, MBBS, FCCP; Wai-cho Yu, MBBS, FCCP; Kam-shing Tang, MBBS; Kahlin Choo, BMBS, FCCP; Moira Mo-wah Chan-Yeung, MBBS, FCCP; on Behalf of the Hong Kong Thoracic Society and American College of Chest Physicians (Hong Kong and Macau Chapter)

Author and Funding Information

Chest. 2006; 129(2):384-392. doi:10.1378/chest.129.2.384

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FEV6 could replace FVC?

- FEV6 is suggested as a surrogate of FVC
- 99 % of the FVC can be obtained in the first 6.64s for patients with FEV1/FVC ratio as low as 50 %
- The FEV1/FEV6 ratio below LLN has a positive and negative predictive value of 97 % for diagnosis of airway obstruction
- When using fixed cut-offs, one may refers to the conclusion by two large population studies that FEV1/FEV6 < 0.73 is an valid alternative to the FEV1/FVC < 0.70 to diagnose airflow obstruction

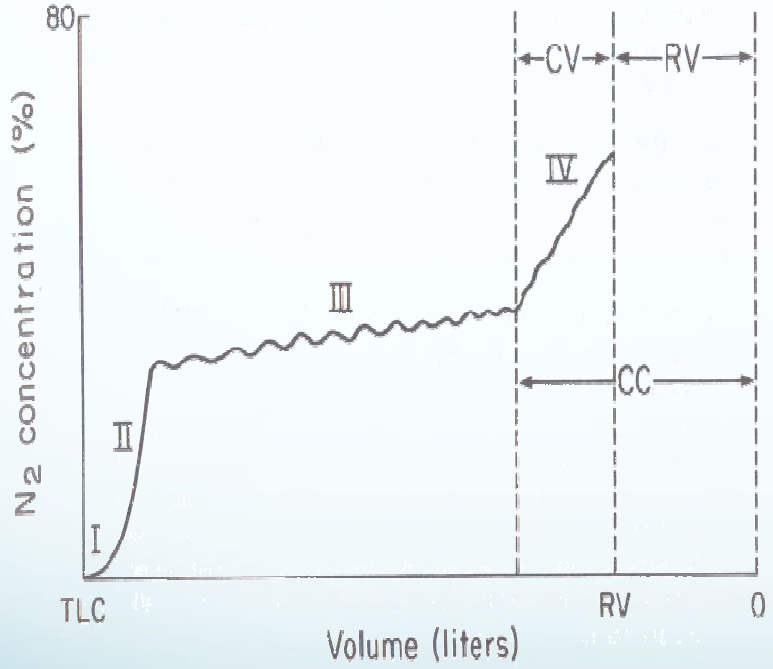
HOW TO MEASURE SMALL AIRWAY ???

- **FEF 25%-75%** (also called maximum mid expiratory flow rate MMFR):
- average flow during the middle half of the FVC maneuver
- In the presence of borderline value of FEV1/VC a reduced FEF25-75 may suggests airflow limitation
- wide variability of FEF25-75
- **=> should not be used alone**

FEV3/FVC

- More sensitive and reliable index to identify early expiratory flow limitation when compared to FEF25-75
- While a decrease in FEV1/FVC reflects reduction in short-time-constant lung units, a decrease in FEV3/FVC or increase in the fraction that had not been expired during the first 3 seconds (1-FEV3/FVC) represents an increase in long-time-constant lung units
- Therefore these indices should be sensitive in detecting early airflow limitation.
- The variability of FEV3/FVC is much lower than FEF25-75 and also lower than that of FEV1/FVC in a large population
- Prediction equations for FEV3 and FEV3/FVC have been published
- FEV3 and FEV3/FVC however are not yet included as a standard parameter by the ATS/ERS1

Nitrogen washout test-Closing volume



Phase I-
Pure O2 Gas from the anatomic deadspace

Phase II-
Rapid rise of N2, coming from both bronchial and alveolar areas (50% deadspace & 50% alveolar)

Phase III-
The plateau phase with gas coming from alveoli. slope is measure of inequality of ventilation

Phase IV-
Closure of the airway in lower lung and emptying of the apices (high in amount of nitrogen)

- **Closing volume (CV):** *lung volume from the beginning of airway closure to the end of maximal expiration.*

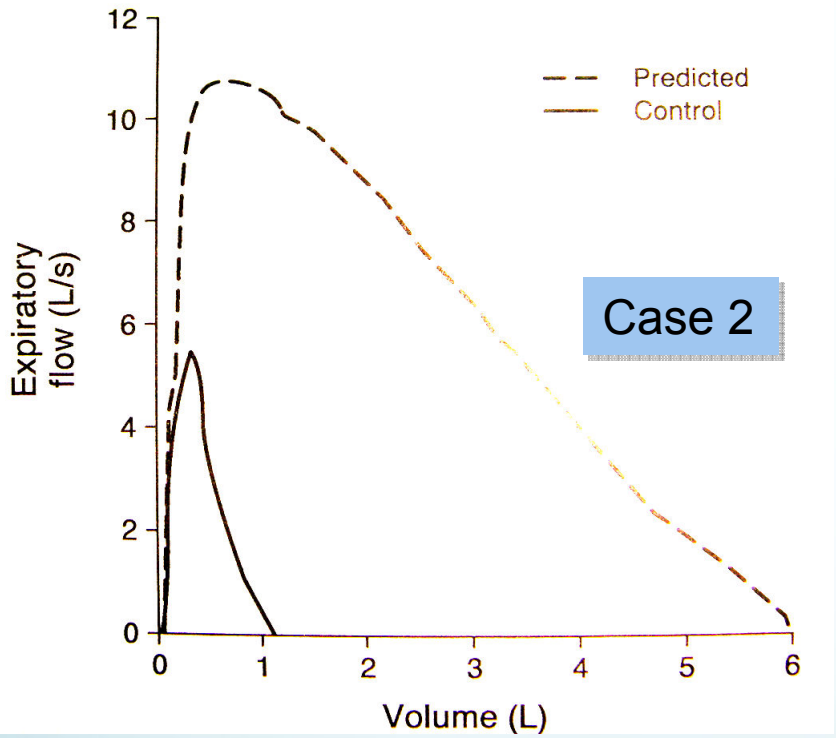
- In normal, young individuals, the CV is about 10% of vital capacity or 0.4-0.5 L.

- **Closing capacity (CC):** lung volume at which small airways in the dependent part of the lung close

閉合容量 (CC) : 閉合容量(CV)與殘氣(RV)之和 **CC=CV+RV**

- **Small airway disease:**
  - **Steeper slope of Phase III (ventilation inhomogenicity)**
  - **Increase in CV**

CASE 2



30/F, non smoker
Progressive dyspnoea and decrease exercise tolerance
P/E: joint pain and tightening of skin

FVC:	1.12 (19% predicted)
FEV1:	1.04 (21 % predicted)
FEV1/FVC:	93%
FEF 25-75:	2.2 (48% predicted)
MVV	81(43% predicted)
TLC	2.09 (28% predicted)
RV/RLC:	44 (232% predicted)
DLCO	9 (26 % predicted)

INTERPRETATION

- Restrictive pattern
  - Steep slope of FV curve
  - Normal FEV1/FVC ratio,
  - TLC: decreased
  - Decrease DLco: lung parenchyma disease
- Scleroderma with interstitial fibrosis

Restrictive lung diseases

Intrapulmonary Cause

- Fibrosis/ inflammation:
  - Pulmonary fibrosis and interstitial pneumonitis
  - BOOP
  - HistiocytosisX
- Infection:
  - Pneumonia
- Neoplasms,
  - e.g. carcinomatosis
- Sarcoidosis
- Asbestosis
- Ateletasis

Extrapulmonary Cause

- Pleural cavity:
  - Pleural effusion, pneumothorax, fibrothorax, cardiac enlargement
- Neuromuscular
  - Diaphragmatic paralysis
  - Neuromuscular diseases e.gMND, MG, polio etc
- Chest wall
  - Kyphoscoliosis
  - Ankylosingspondylitis
  - Thoracoplasty
  - Ascites
  - pregnancy

Lung function pattern in restrictive diseases:

INTRAPULMONARY

Dynamic:

- FVC, FEV1 decrease
- FEV1/FVC ratio normal or elevated
- *MVV normal* (decreased volume compensated by increase in RR)
- *Slope of FV curve: increase*

Static:

- TLC, RV, FRC: decrease

Diffusion:

- **DLco decrease**
- **Kco: normal or decrease**

Resp muscle

- PEmax, PImax not affected

EXTRAPULMONARY

Dynamic:

- FVC, FEV1: decrease
- FEV1/FVC: normal
- MVV decreased
- **Slope of FV curve: normal or decreased**

Static:

- TLC, RV, FRC: decreased

Diffusion:

- *DLco: normal*
- *Kco: normal*

Resp muscle:

- PImax, PEmax: normal *(decreased when in neuromuscular disease)*

CASE 3

30/F, non smoker
Progressive dyspnoea and decrease exercise tolerance
P/E: joint pain and tightening of skin

FVC: (80% predicted)
FEV1: (80 % predicted)
FEV1/FVC: 93%
FEF 25-75: 2.2 (48% predicted)

TLC (90% predicted)

DLCO 9 (26 % predicted)

Disproportionate decrease in DLCO

- ? Pulmonary vascular disease
- ? Early interstitial lung disease

Diffusion capacity

- The diffusion capacity (DLco)
  - Measures ability of lungs to transport inhaled gas from alveoli to pulmonary capillaries
- A sensitive index of the integrity of blood gas interface
- Amount of oxygen transferred is determined by
  - Area and thickness of alveolar-capillary membrane
  - Driving pressure (the difference in oxygen tension between alveolar gas and the venous blood)
  - hemoglobin concentration
  - cardiac output
- Diffusion capacity of oxygen is difficult to measure, so diffusion capacity of CO_2 is used

- Technique: single breath method
- Subject exhales to residual volume and then inhaled a gas mixture containing very low concentration of CO and inert gas
- After maximal inhalation to TLC, hold breath for 10 sec, and gas is collected and analyzed
- Conc of exhaled CO and He was measured and the TLC and DLCO was calculated

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**
  - Supine position, (higher perfusion and blood volume of upper lobe in this position)
  - Exercise(increase in blood volume)

Causes of a decreased diffusion capacity

Decrease area of diffusion

- Emphysema
- Lung/lobe resection
- Bronchial obstruction
- Multiple pulmonary emboli
- Anaemia

Increase thickness of alveolar capillary membrane

- Idiopathic pulmonary fibrosis
- CHF
- Asbestosis
- Sarcoidosis
- Collagen vascular disease: scleroderma, SLE
- drug induced alveolitis or fibrosis
- Hypersensitivity pneumonitis
- Histiocytosis X
- Alveolar proteinosis

Interpretation of DLCO

Increased DLCO

- Polycythemia
- Severe obesity
- Asthma
- Pulmonary hemorrhage
- Left-to-right intracardiac shunting
- Mild left heart failure – increased pulmonary capillary blood volume
- Exercise just prior to the test – increased cardiac output

Low DLCO with normal spirometry

- Anemia – mild decrease
- Pulmonary vascular disease – mild to severe decrease
- Early interstitial lung disease – mild to moderate decrease

Low DLCO with obstruction

- Emphysema
- Cystic fibrosis
- Bronchiolitis
- Lymphangioleiomyomatosis

Low DLCO with restriction

- Interstitial lung disease
- Pneumonitis

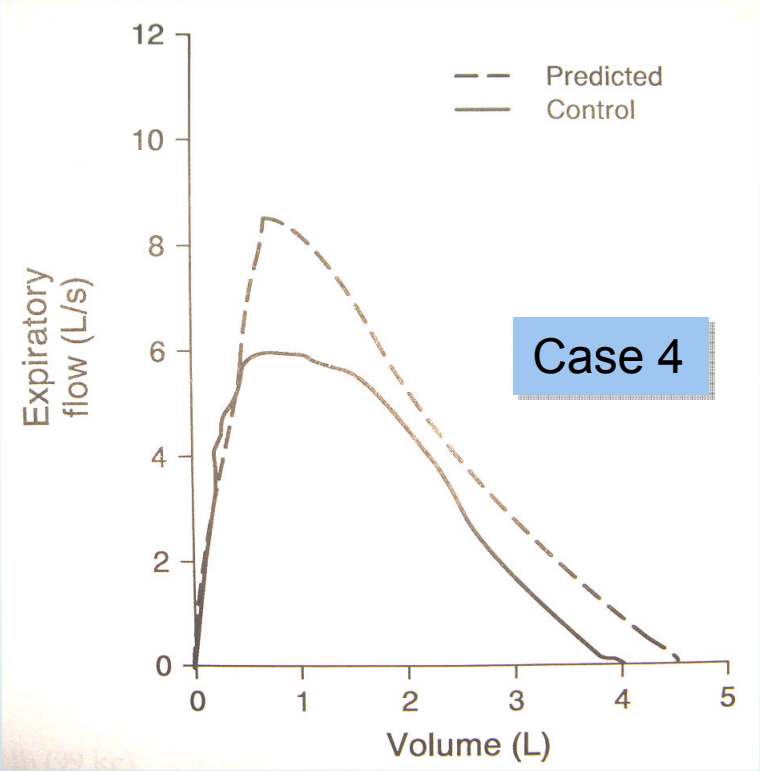
Other

- Anemia – reduces DLCO
- Carboxyhemoglobin – reduces DLCO
- Altitude – increases DLCO

Kco

- Kco=DLco/VA (alveolar volume)
- Is volume standardized measure of Dlco
- Intrinsic property of alveolar-capillary membrane
- Kco is reduced in emphysema and intrathoracic causes of restrictive lung disease, it is normal in extrathoracic causes of restrictive lung disease and pnemonectomy
- Kco is elevated when there is **discrete loss** of alveolar volume, high cardiac output or pulmonary hemorrhage

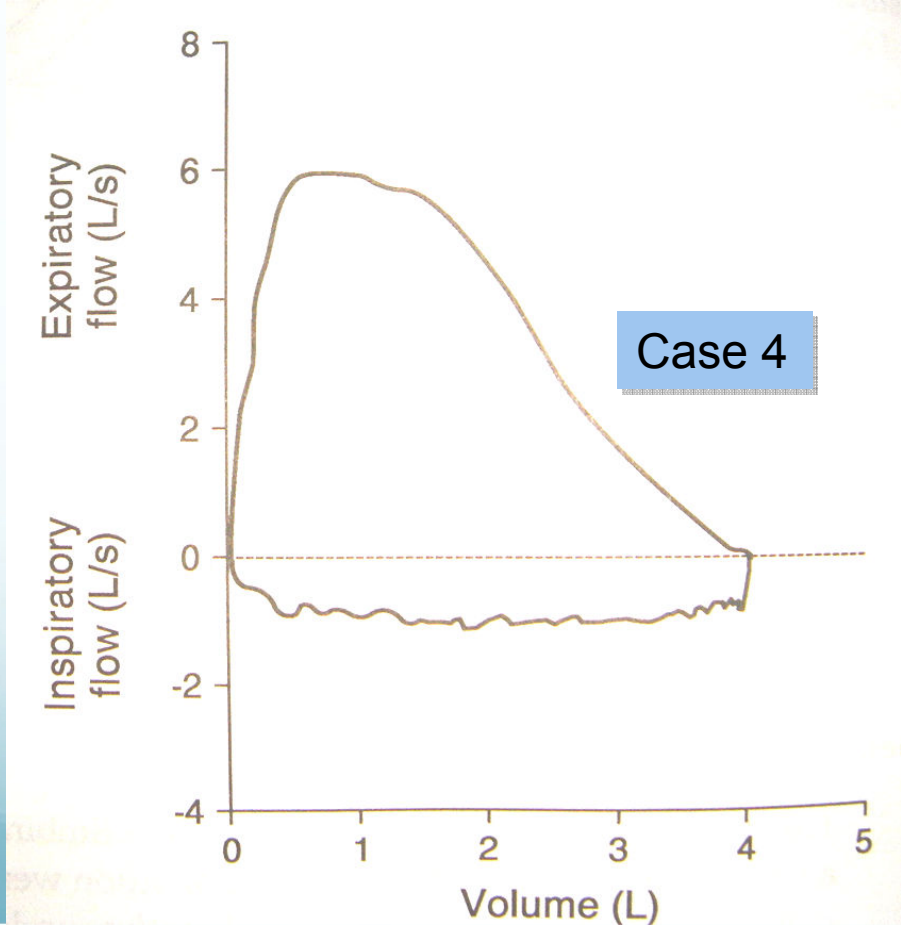
CASE 4



50/M, non smoker
Hx of bulbar poliomyelitis 19 yrs ago
c/o: SOB on climbing stairs

FVC:	4.02 (87% predicted)
FEV1:	3.23 (88% predicted)
FEV1/FVC:	80%
FEF 25-75%	3.0 (88% predicted)
MVV	46 (31% predicted)

- Normal contour of FV curve
- Unexplained isolated decreased in MVV
  - Poor effort, major airway lesion, neuromuscular problems
- FV loop show variable extrathoracic central airway obstruction



Maximal voluntary ventilation (MVV)

- Volume of air exhaled in 12 seconds during rapid, forced breathing (<15sec because may produce syncope)

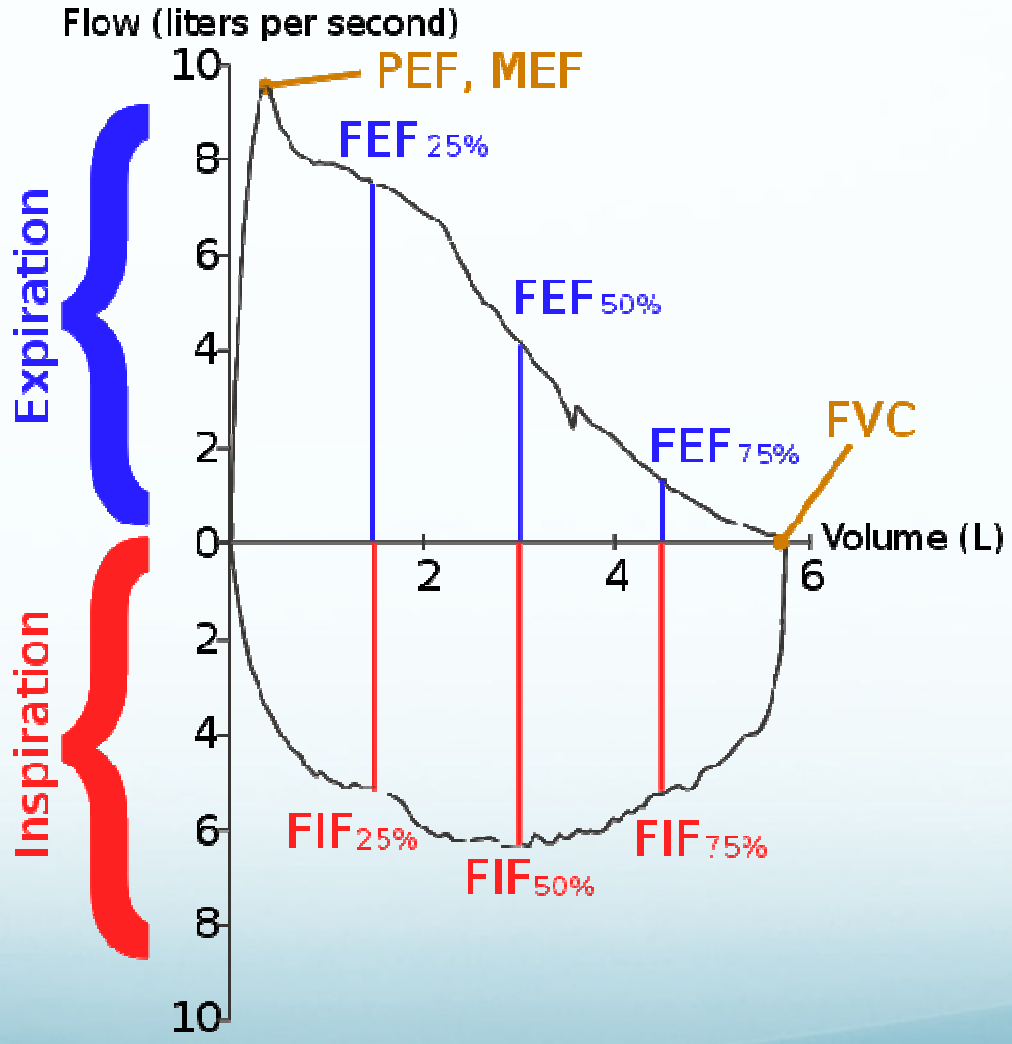
- A measure of overall function of the resp system, affected by airway resistance, resp muscles, compliance of lung, ventilatory control system

- Acceptability criteria:
  - Tracing shows continous, rhythmic effort for at least 12 seconds
  - End expiratory lung volume is relatively constant
  - 2 acceptable maneuvers obtained, with values within 10%

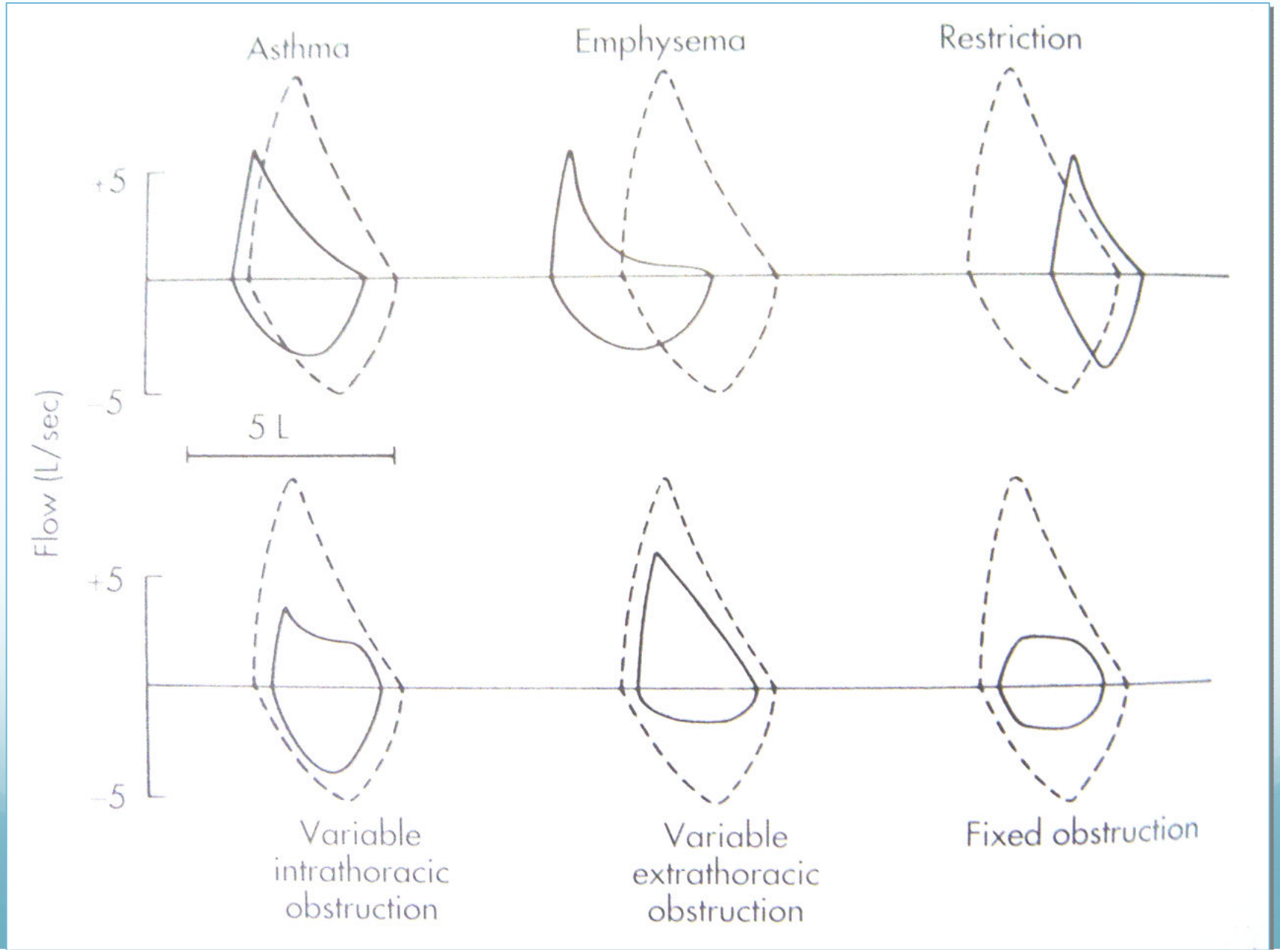
Maximal voluntary ventilation (MVV)

- Approximately equal to FEV1 x40;
- If lower than the predicted value:
  - poor effort or fatigue
  - Major airway obstruction
  - Resp muscle weakness
  - (less specific when in advanced level of obstructive disease)

Flow- Volume loop



Different characteristic flow volume loop pattern



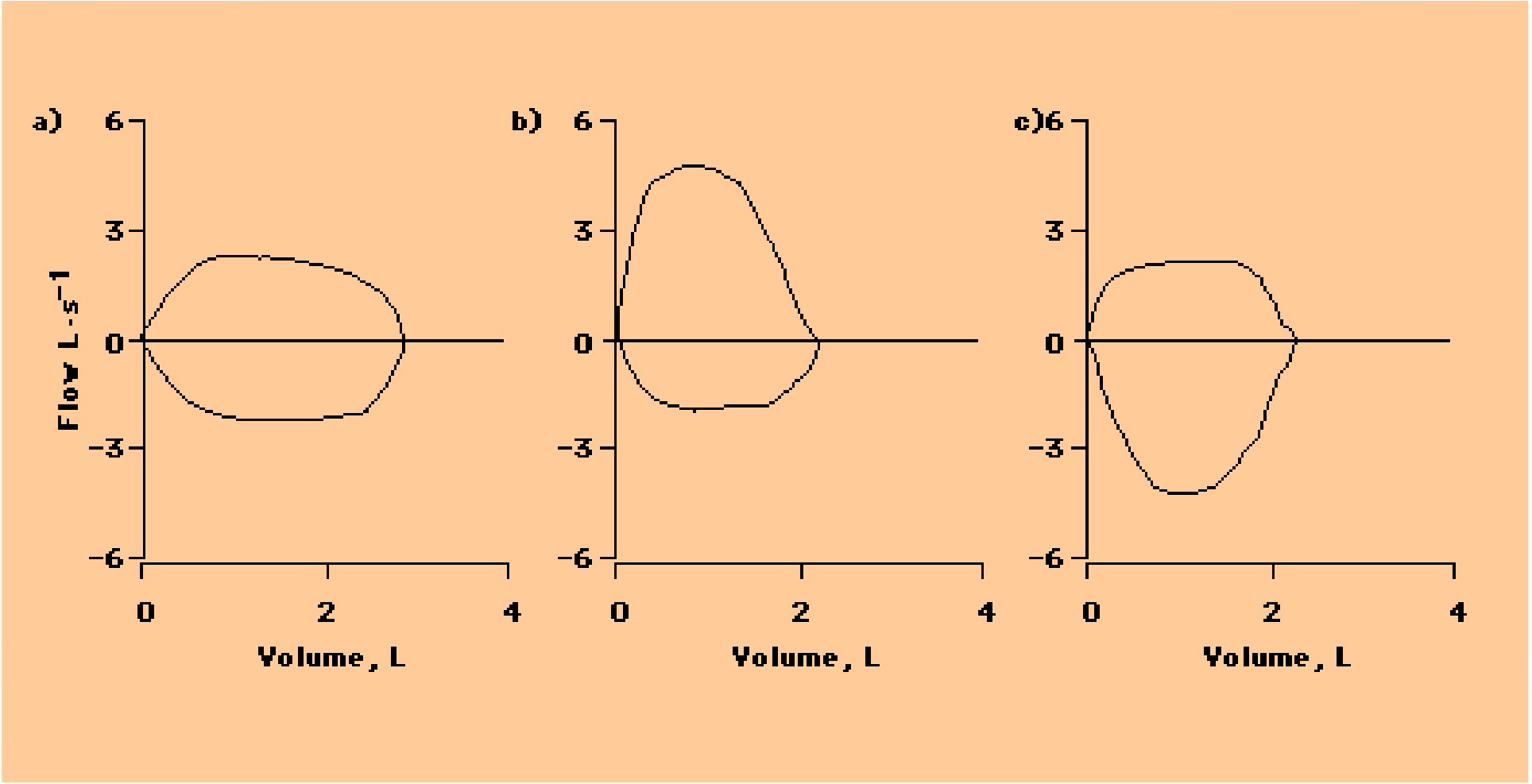
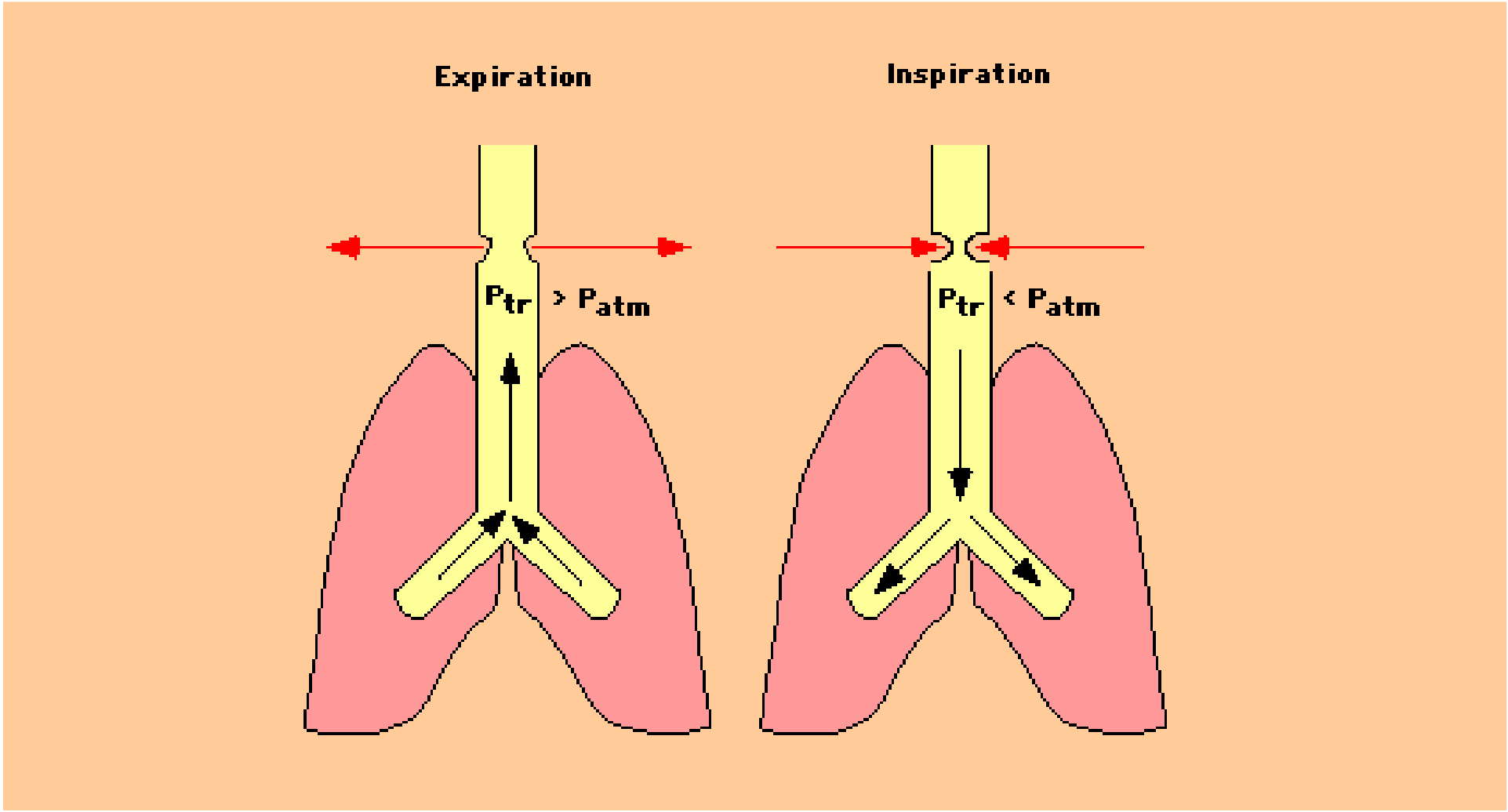
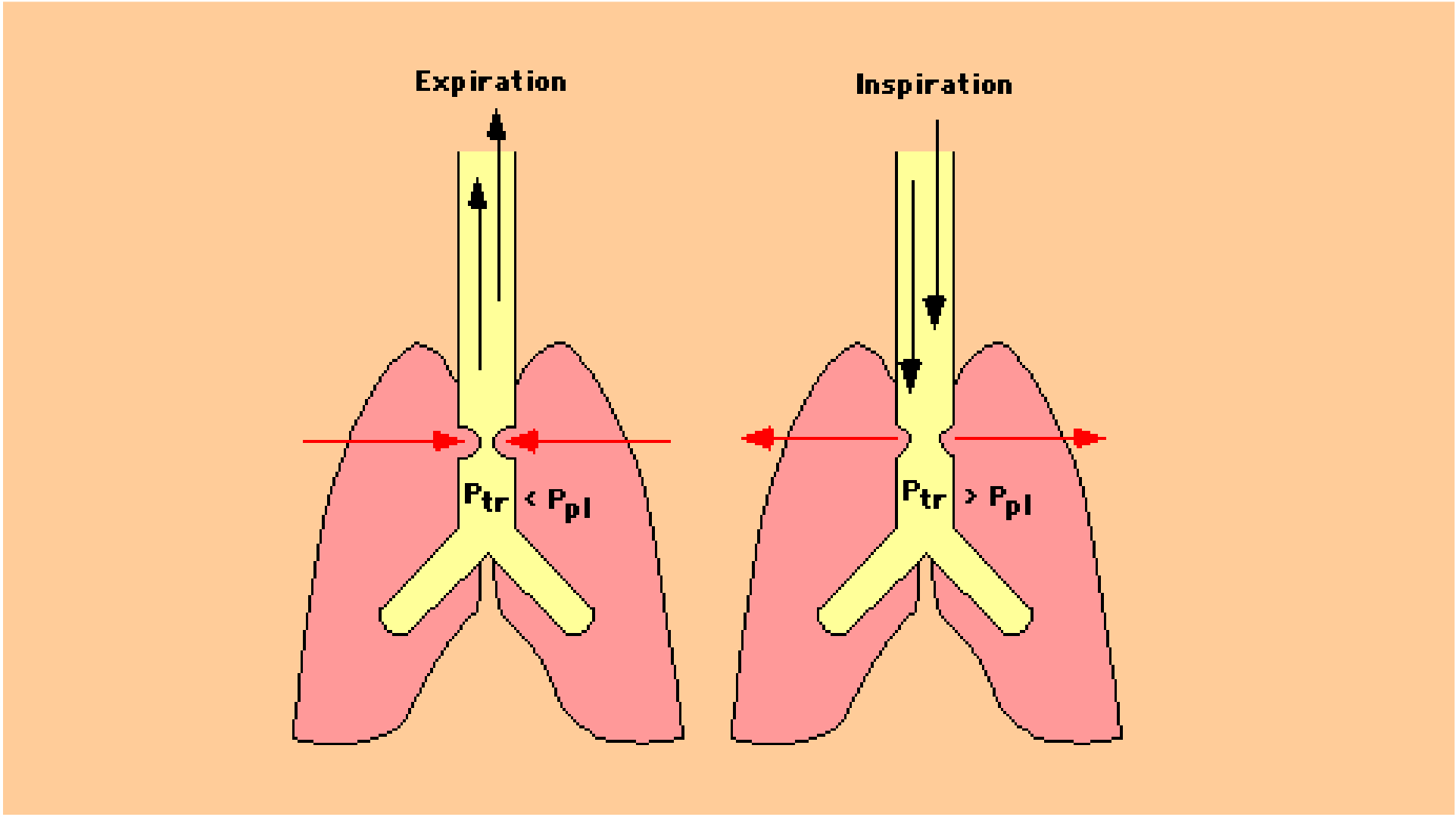


Figure 3 Idealised examples of a) fixed, b) variable extrathoracic, and c) variable intrathoracic airway obstruction. Pellegrino, R, Viegi, G, Brusasco, V, et al. Interpretative strategies for lung function tests. ATS/ERS task force: standardisation of lung function testing. Eur Respir J 2005; 26:948.



Effect of dynamic extrathoracic airway obstruction Effects of forced expiration and inspiration in dynamic extrathoracic airway obstruction. Left, during forced expiration, intratracheal pressure (Ptr) exceeds the pressure around the airway (Patm), lessening the obstruction. Right, during forced inspiration, when intratracheal pressure falls below the atmospheric pressure, the obstruction worsens resulting in flow limitation. (Redrawn from Kryger, M, Bode, F, Antic, R, et al, Am J Med 1976; 61:85.)



Effects of dynamic intrathoracic airway obstruction Left panel, during forced expiration, the intrathoracic intratracheal pressure (Ptr) is less than the pressure in the pleural pressure (Ppl), worsening the obstruction. Right, during forced inspiration, intratracheal pressure exceeds the pleural pressure, lessening the degree of obstruction. (Redrawn from Kryger, M, Bode, F, Antic, R, et al, Am J Med 1976; 61:85.)

Table 10. Lung Function Parameters Capable of Differentiating Extrathoracic From Intrathoracic Obstruction†

	Extrathoracic		Intrathoracic obstruction
	Fixed	Variable	
PEF	Decreased	Normal or decreased	Decreased
MIF50	Decreased	Decreased	Normal or decreased
MIF50/MEF50	~1	<1	>1

PEF: peak expiratory flow; MIF50: maximum inspiratory flow at 50% of forced vital capacity (FVC); MEF50: maximum expiratory flow at 50% of FVC.

† Pellegrino, R, Viegi, G, Brusasco, V, et al. Interpretative strategies for lung function tests. ATS/ERS task force: standardisation of lung function testing. Eur Respir J 2005; 26:948.

- Variable intrathoracic lesions
  - Tumor of lower trachea
  - Tracheomalacia
  - Strictures
  - Wegener's granulomatosis or relapsing polychondritis

- Variable extrathoracic lesions:
  - Vocal cord paralysis (due to thyroid operation, tumor invading recurrent laryngeal nerve, amyotrophic lateral sclerosis, post polio)
  - Subglottic stenosis
  - Neoplasm (primary hypopharyngeal or tracheal, metastatic from primary lesion in lung or breast)
  - Goiter

- Fixed lesions
  - Fixed neoplasm in central airway (at any level)
  - Vocal cord paralysis with fixed stenosis
  - Fibrotic stricture

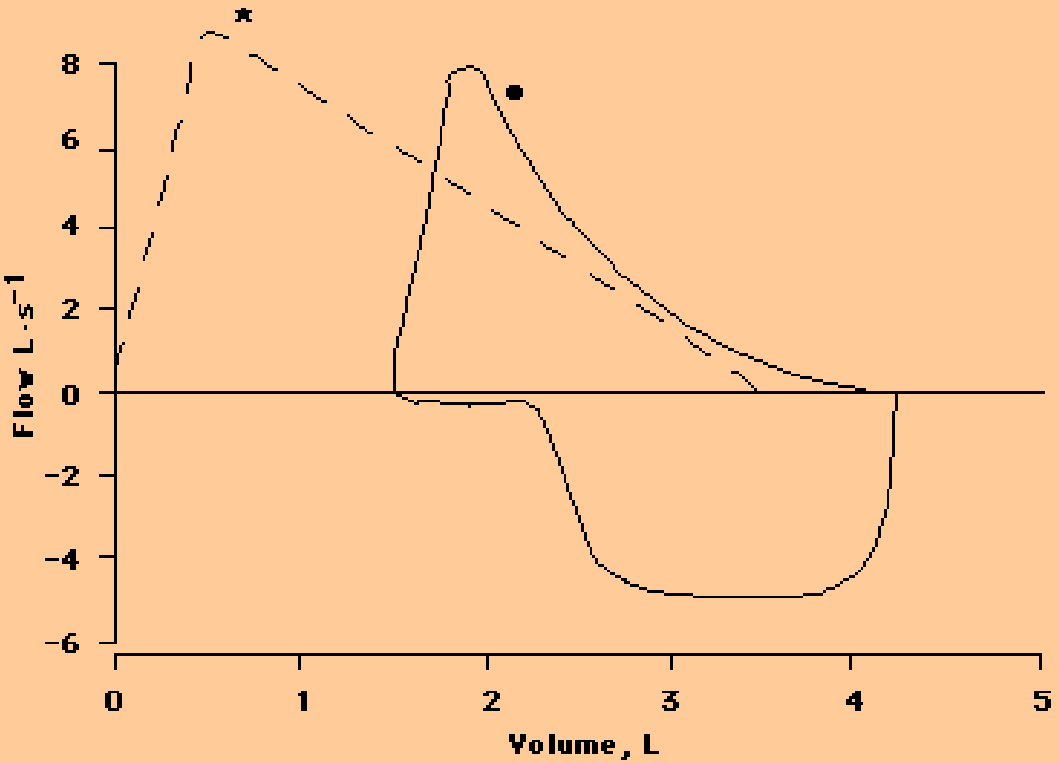
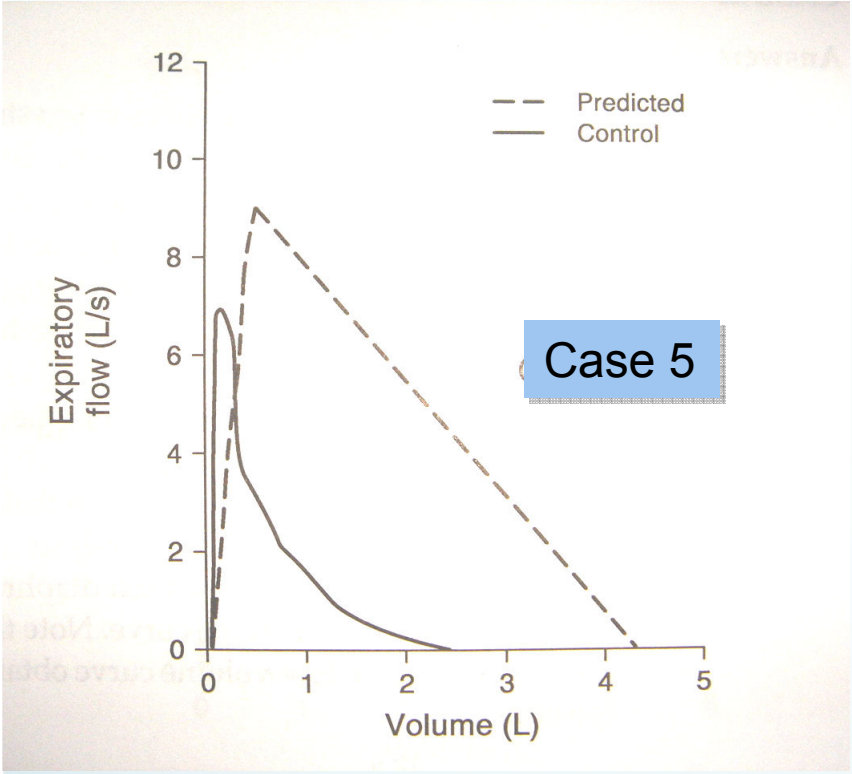


Figure 4 Example of unilateral main bronchus obstruction due to a valve-like mechanism occluding the main left stem bronchus during inspiration as a result of a surgical scar. There is a delay in gas filling towards the end of the forced inspiration as evidence of the variable unilateral main bronchus obstruction (forced expiratory volume in one second (FEV1): 76%; FEV1/vital capacity: 70%; peak expiratory flow: 93%; total lung capacity: 80%). *: predicted expiratory flow-volume loop; ●: recorded maximum inspiratory and expiratory flow-volume loops. Pellegrino, R, Viegi, G, Brusasco, V, et al. Interpretative strategies for lung function tests. ATS/ERS task force: standardisation of lung function testing. Eur Respir J 2005; 26:948.

CASE 5



68/M, chronic smoker
c/o: SOB especially when lying down,
not much dyspnoea when walking

FVC	2.43 (56% predicted)
FEV1	1.59 (52% predicted)
FEV1/FVC	66%
FEF 25-75	0.7 (26% predicted)
MVV	87 (75% predicted)
TLC	4.95 (63% predicted)
RV/TLC	51% (116% predicted)
DLCO:	28 (90% predicted)

INTERPRETATION

- Mild obstructive component as shown by mild decrease in FEV1/FCV ratio
- TLC decreased → mixed restrictive disease
- Normal DLco: extrapulmonary causes

- PIMax and PEMax done: decreased
- Fluoroscopy done: confirmed diaphragmatic paralysis

Respiratory muscle power

- Neuromuscular causes of resp failure:
  - CNS system
  - Neuropathy
  - MN junction
  - Muscle disease

- Vital capacity is a useful screening test
- Sensitivity of test may be increased by measurement supine(weight of abdominal viscera give additional load to diaphragm), a disparity of greater than 25% of VC is indicative of NM disease
- A normal supine VC exclude clinically important muscle weakness
- Also best mean of monitoring of progress of resp muscle impairment
- If VC is <30ml/kg → impaired ability to cough
- In chronic resp muscle disease, VC of less than 1/3 of normal predict impending resp failure

- Arterial pCO_2 raised
- TLC, FVC decreased, RV increased
- Kco increased

- MIP
- MEP

- Transdiaphramatic measurement
  - Sniff Pdi
  - Twitch Pdi
- Radiological assessment of muscle strength (insenstivitive)

PEmax/PImax

- The strength of expiratory muscles is measured near the TLC and that of inspiratory muscles is measured near the residual volume
- PEmax around twice of PImax

Normal values for PImax/PEmax

TABLE 9-1. Normal values for maximal respiratory pressures, by age

	Age (yr)				
Pressure	*20–54*	*55–59*	*60–64*	*65–69*	*70–74*
PImax, cm H_2O*					
Male	−124 ± 44	−103 ± 32	−103 ± 32	−103 ± 32	−103 ± 32
Female	−87 ± 32	−77 ± 26	−73 ± 26	−70 ± 26	−65 ± 26
PEmax, cm H_2O*					
Male	233 ± 84	218 ± 74	209 ± 74	197 ± 74	185 ± 74
Female	152 ± 54	145 ± 40	140 ± 40	135 ± 40	128 ± 40

PEmax, maximal expiratory pressure; PImax, maximal inspiratory pressure.
*Numbers represent mean ± 2 standard deviations.

- PEmax:
  - Subject inhale maximally, hold the rubber tubing firmly against the mouth and exhales as hard as possible, the highest positive pressure maintained for 0.9sec is recorded

- PImax:
  - Subject exhale to RV, hold the rubber tubing against the lip and suck as hard as possible, the highest negative pressure sustained for 2 seconds is recorded

- Indications for measuring resp muscle strength
  - In patient with neuromuscular disease
  - In patient with isolated unexplained decrease in vital capacity or MVV; (may be early signs of respiratory muscle weakness)
  - To assess weaning potential, PImax < -20 cmH2O and PEmax >+50cmH2O are favourable

Thank You