Pulmonary Function Testing

Module L

Objectives

- State the indications for pulmonary function testing.
- Describe how each of the following tests are performed:
  - Helium Dilution
  - Nitrogen Washout
  - Body Plethysmography
  - Pre-/Post-bronchodilator Study
  - Flow-Volume Loop
  - Bronchial Provocation
  - Exercise Testing
  - MIP and MEP

Objectives

- Given a set of pulmonary function results, determine
  - Percent predicted
  - Type of defect (e.g. restrictive, obstructive)
  - % improvement (Pre-/Post-) and significance
- Given a flow-volume loop, determine if an obstructive defect is due to a fixed, extrathoracic, or intrathoracic defect.

Objectives

- Describe the key steps in pulmonary function testing
- Describe the process of calibration of pulmonary function equipment.
- Differentiate between volume-displacing spirometers and flow-sensing spirometers.
- Describe how pneumotachs measure volume.
- List the advantages and disadvantages of both volume-displacing and flow-sensing spirometers.

Objectives

- Describe the meaning of the following ATS acceptability criteria:
  - Good start of the test
  - Good Effort
  - No coughing
  - No variable flows
  - No early termination
- Given a spirometry error code, state the cause of the error and the proper corrective measure to be undertaken.
- Given PFT results, determine the severity of an obstructive disorder.

Specialty Examinations

- Certification Examination for Entry Level Pulmonary Function Technologists
  - (CPFT)
- Registry Examination for Advanced Pulmonary Function Technologists
  - (RPFT)

Indications for Pulmonary Function Testing

- Identify the presence or absence of lung dysfunction suggested by history or physical signs / symptoms.
  - Normal, Obstructive, Restrictive
  - Diffusion Defects
  - ATS recommends testing in any patient over 45 years of age with a history of cigarette smoking or under 45 years of age with symptoms.

Indications for Pulmonary Function Testing

- Quantify the severity of known lung disease.
- Identify and quantify changes in pulmonary function over time.
  - Is the disease progressing?
  - Is the disease reversible?
  - Is therapy working?

Indications for Pulmonary Function Testing

- Assess the potential effects or response to environmental or occupational exposure.
- Assessment of Post-Op Risk
  - Surgical patients (thoracic or abdominal)
- Pulmonary Disability
  - Rehabilitation
  - Legal
  - Military

Pulmonary Function Testing does not diagnose specific pulmonary disease.

PFT Predicted Values

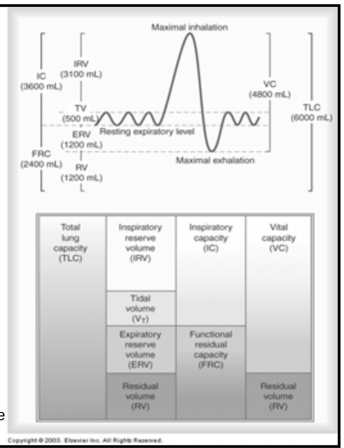
- Based on
  - Age
  - Gender
  - Height
  - Race (?)
  - Weight (?)
- Reference Values
  - Regression Formula (Egan p. 422)
    - Adult: Morris, Crapo, Knudson
    - Pediatrics: Hsu and Polgar

Normal Values

- What is generally "accepted"
  - 80-120 % of predicted is considered "normal".
    - Larger errors with flowrates ($FEF_{25-75\%}$)
  - FEV_1/FVC of greater than 70% "normal"
- What ATS says should be used
  - 5th percentile of predicted (LLN)
    - Allows for false positives
    - Predicted value – 1.645 x SEE
  - FEV_1/FVC "normal" are subject to significant variability and should not be used.

- •4 VOLUMES
  - •Tidal Volume: 500 mL
  - •Inspiratory Reserve Volume: 3100 mL
  - •Expiratory Reserve Volume: 1200 mL
  - •Residual Volume: 1200 mL
- •FOUR CAPACITIES
  - •Inspiratory Capacity: 3600 mL
  - •Functional Residual Capacity: 2400 mL
  - •Vital Capacity: 4800 mL
  - •Total Lung Capacity: 6000 mL

Normal 20 year old, 70kg male



Lung Volume Measurement

- RV, FRC, TLC cannot be directly measured
- Four Methods
  - Closed Circuit: Helium Dilution
  - Open Circuit: Nitrogen Washout
  - Body Plethysmography
    - Thoracic Gas Volume (TGV) vs. FRC
  - Chest X-ray - TLC
    - Planimeter and ellipse method
- Key Points
  - Tests are begun at the end of a normal exhalation (FRC).
  - Highly reproducible and not effort dependent

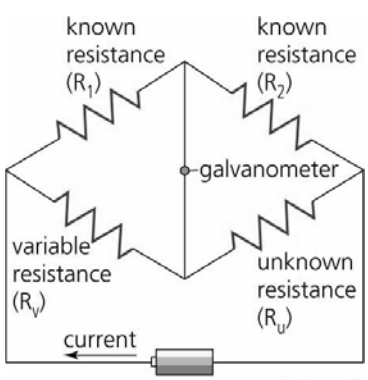
HELIUM DILUTION

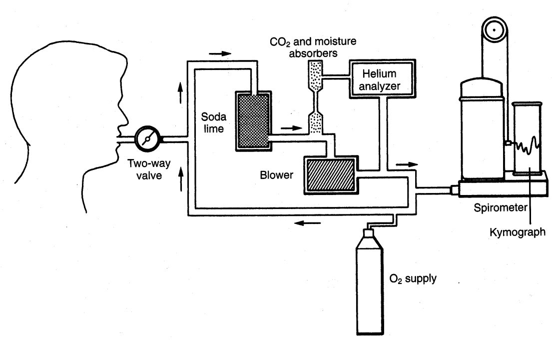
- Requires the patient to re-breathe a helium gas mixture of a known concentration through a closed circuit from a spirometer of a known volume.
- Helium is inert.
- Re-breathing allows for the equilibration of helium concentration between spirometer and lung.
  - Carbon dioxide scrubber (soda lime) needed.
  - Equilibration time is usually about 3 minutes.

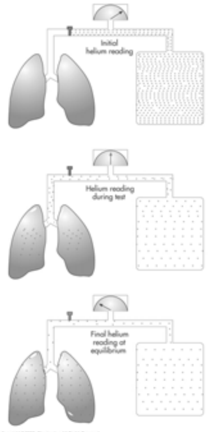
HELIUM DILUTION

- Oxygen is added to spirometer to account for oxygen depleted by patient (spirometer volume remains constant).
- FRC = (%He $_{initial}$ - %He $_{final}$)/% He $_{final}$ x Volume $_{Spirometer}$
- He analyzer (Katharometers)
  - Wheatstone bridge
  - Thermal conductivity

Wheatstone Bridge







HELIUM DILUTION CALCULATION

- **GIVEN:**
  - **Initial Helium Percentage: 10%**
  - **Initial Spirometer Volume: 3 liters**
  - **Final Helium Percentage: 6%**

FRC = (%He $_{initial}$ - %He $_{final}$)/% He $_{final}$ x Volume $_{Spirometer}$

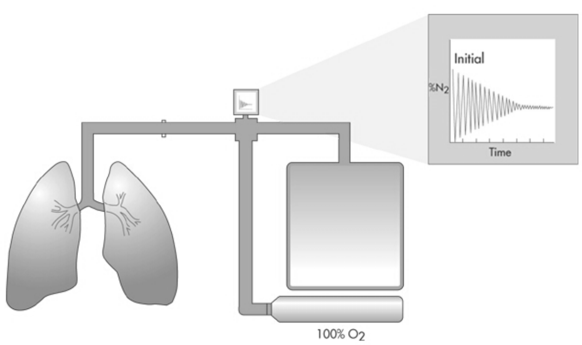
FRC = (10%-6%)/6% x 3 liters
FRC = 4%/6% x 3 liters
FRC = .6667 x 3 liters = 2 liters
MUST CONVERT FROM ATPS to BTPS
FRC – ERV (from spirometry) = RV
FRC + IC = TLC

Problems with He Dilution

- **No Leaks can be present from mouth, nose, ears or equipment**
  - **A ruptured tympanic membrane will result in inaccurate readings**

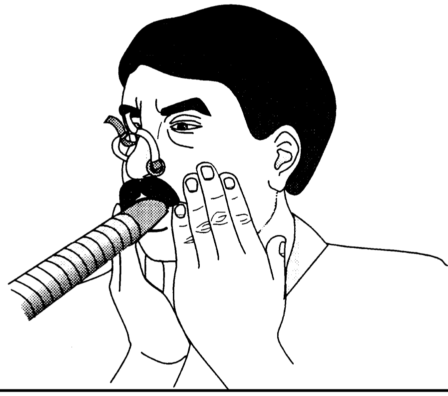
NITROGEN WASHOUT

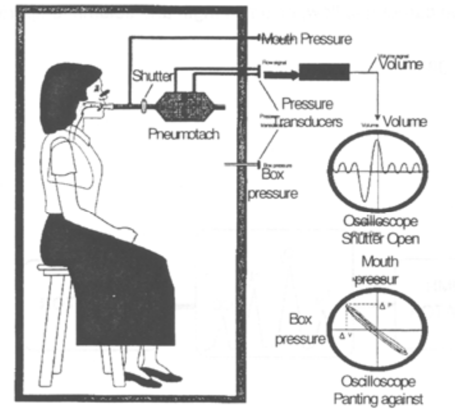
- **The N_2 concentration in the lungs is 75-80%**
- **Patient breaths 100% O2 and washes out the nitrogen.**
  - **The switch to breathing 100% oxygen must come at the end of a normal exhalation (i.e. at FRC).**
- **The test continues until the N_2 is less than 1%**
  - **3-4 minutes**
  - **COPD washout time may exceed 7 minutes**
- **Open circuit (no re-breathing)**
- **FRC = (V_E x F_EN_2)/(0.78)**
- **Once FRC is determined, RV and TLC can be calculated**

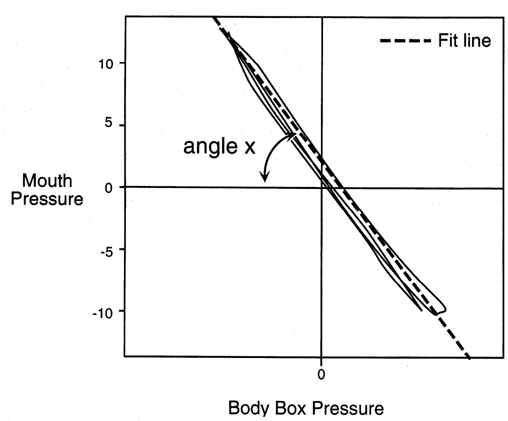


BODY PLETHYSMOGRAPHY

- **Patient breaths normally & at end exhalation (FRC), a shutter is closed and the patient begins to pant**
  - **Panting Frequency is 1 Hertz (Hz) (one cycle per sec)**
  - **One-two breaths/sec with glottis open**
- **Simplified explanation for a complex formula.**







Thoracic Gas Volume

- **Two pressure changes are measured**
  - **Drop in mouth pressure as patient attempts to inhale.**
  - **Increase in chamber pressure as patient's chest expands.**
- **Volume change is measured in the body box.**
  - **TGV ~ FRC**
  - **Measures ALL gas volume in thorax, even the volume distal to an obstruction.**
- **Boyles Law** $V_1P_1 = V_2P_2$

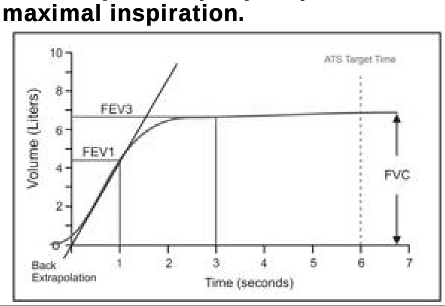
$$V_2 = \frac{V_1 P_1}{P_2}$$

Expiratory Flow Rate Measurements

- **Measures the rate at which gas flows out of the lungs.**
  - **Patency of the airways**
  - **Severity of airway impairment**
  - **Size of the patient's airways**

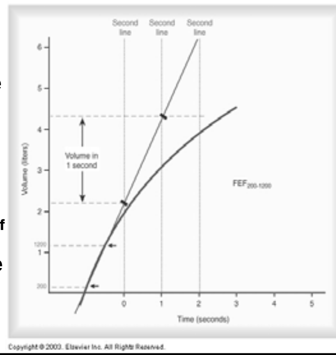
Forced Vital Capacity

- **Volume of gas that can be exhaled as forcefully and rapidly as possible after a maximal inspiration.**



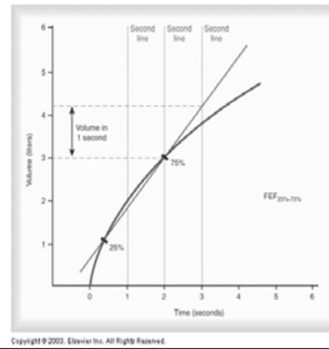
Forced Expiratory Flow$_{200-1200}$

- Maximum expiratory flowrate.
- Average flow rate between 200 and 1200 mL.
  - First 200 mL is ignored because of:
    - Inertia
    - Response time of spirometer
- Good index of the patency of large airways



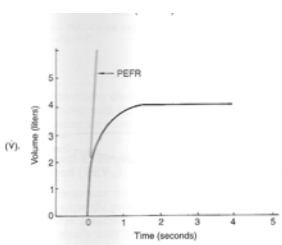
Forced Expiratory Flow$_{25-75\%}$

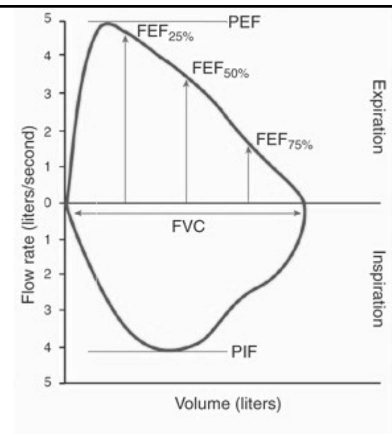
- Maximum midexpiratory flowrate.
- Average flow rate during middle 50% of FVC.
- Can be used to assess the middle sized airways.
  - Caution: Use only as a secondary indice.



Peak Expiratory Flow Rate

- Peak Flow
- Maximum flow rate that can be achieved.
- Easiest measurement for determining "status" of airways.
- Variable results
  - Life of PF meters
- Much easier to read from Flow-Volume Loop.



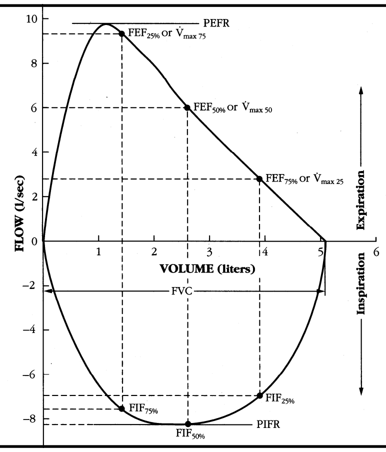


Maximum Voluntary Ventilation

- Largest volume of gas that can be breathed voluntarily in and out of the lungs in one minute.
  - Test usually is performed for 12 to 15 seconds.
  - Very effort-dependent

Flow Volume Loops

- Normal
- Obstructive
- Restrictive
- Fixed
- Variable Extrathoracic
- Variable Intrathoracic



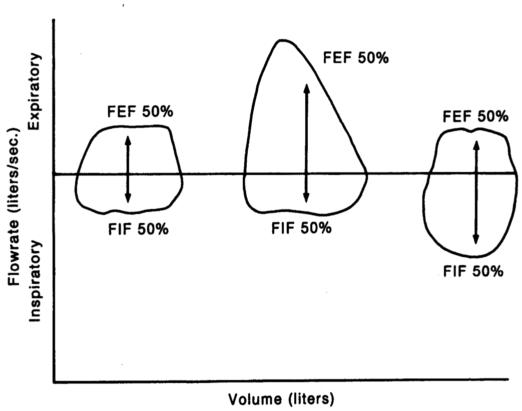
$FEF_{50\%}/FIF_{50\%}$

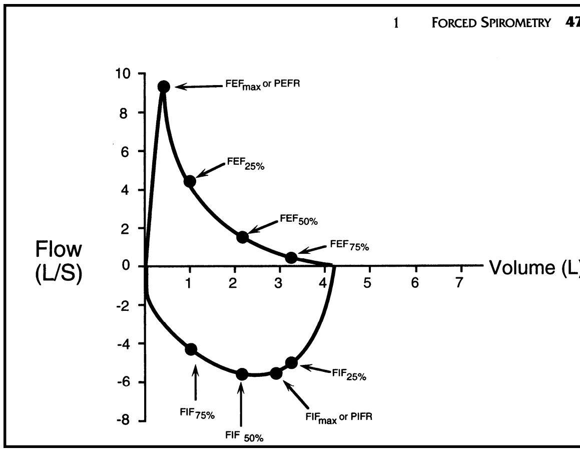
- **This ratio can be used to determine the type of obstructive defect.**
- **Normally this ratio is 0.8 to 1.0**

$$\frac{FEF_{50\%}}{FIF_{50\%}} = 0.8 \text{ to } 1.0$$

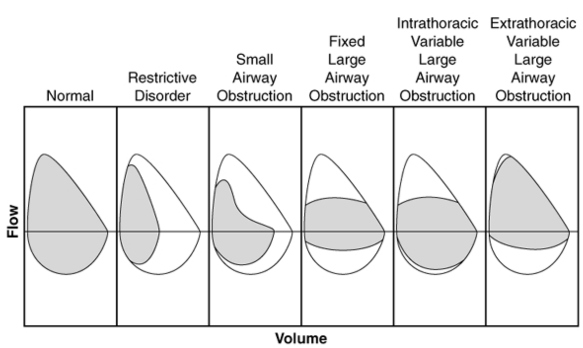
$$\frac{6\ L/sec}{6\ L/sec} = 1$$

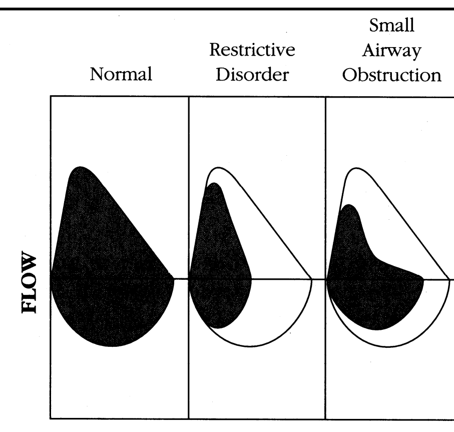
$$\frac{6L/\sec}{7L/\sec} = 0.85$$

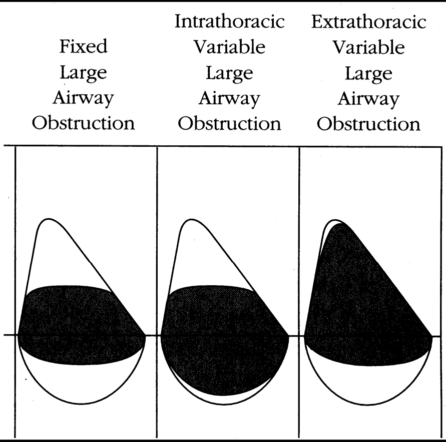




Flow Volume Loops



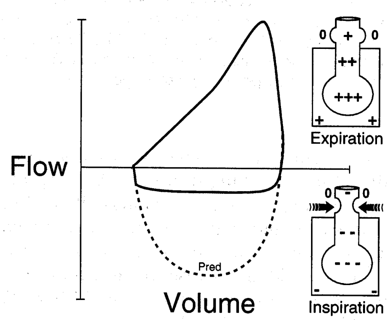


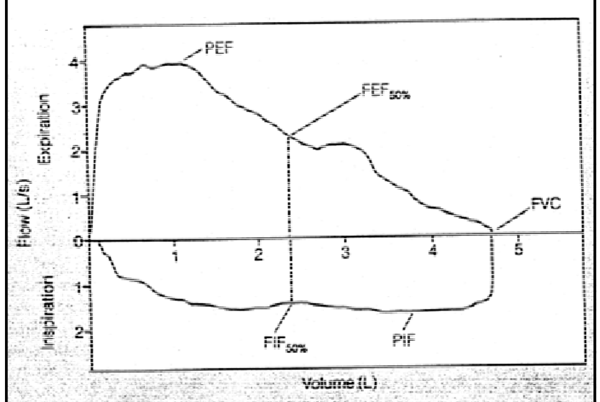


Criteria

- *Three* **acceptable flow volume loops should be obtained**
- **Sharp rise to PEFR; if not suspect poor effort or large airway obstruction**
- **F-V loops are used to detect upper airway obstruction**
  - **Extrathoracic obstruction occurs above the suprasternal notch**
  - **Intrathoracic obstruction occurs below the suprasternal notch**
  - **Fixed obstruction can occur either above or below**

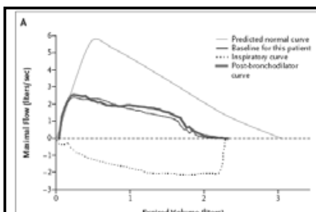
Variable Extrathoracic Obstruction



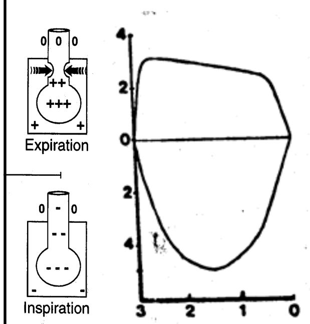


Variable Extrathoracic Obstruction

- **Normal expiratory flows but decreased inspiratory flows**
- **$FEF_{50\%}/FIF_{50\%}$ is greater than 1.0**
- **Causes**
  - **Upper airway tumor**
  - **Edema of epiglottis**
  - **Vocal cord paralysis**
  - **Vocal cord adhesions**
  - **Foreign body in upper airway**

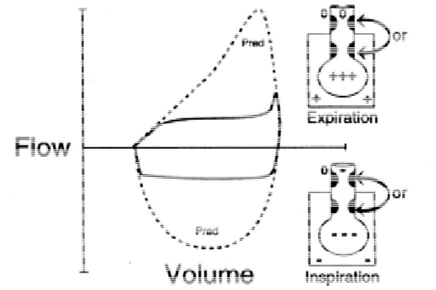


Variable Intrathoracic Obstruction



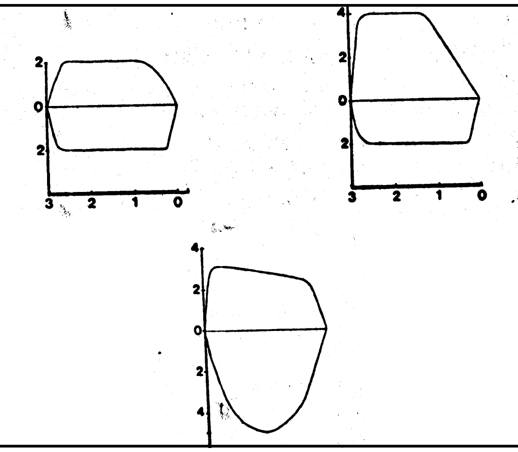
- Tracheomalacia
- Polychondritis
- Tumor near the carina
- Foreign body in trachea
- $FEF_{50\%}/FIF_{50\%}$ is less than 0.8

Fixed Obstruction



Fixed Obstruction

- This results in equally reduced flowrates
- The loop is squared off on both inspiration and expiration
- $FEF_{50\%}/FIF_{50\%}$ is normal
- Causes
  - Vocal cord stenosis (watch after extubation)
  - Goiter
  - Large foreign body
  - Tumor



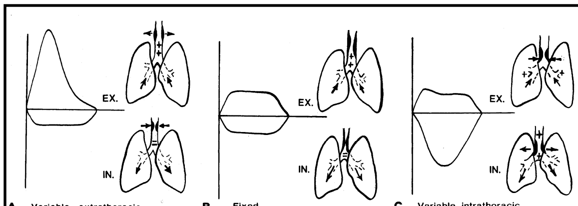


FIGURE 8-8. Flow–volume loop patterns caused by three types of upper airways obstruction (UAO). **(A)** A variable, extrathoracic UAO is commonly due to vocal cord paralysis. The vocal cords are forced wider during forced exhalation but narrow during forced inhalation (because of negative pressure in the airway), creating an inspiratory plateau. **(B)** A fixed UAO, such as tracheal stenosis, is unaffected by pressure differences across the airway, resulting in limited flow (a plateau) during both forced exhalation and inhalation. **(C)** Less commonly, a variable, intrathoracic UAO, such as a tumor near the carina, opens during forced inhalation, but narrows during forced exhalation, limiting expiratory flow. (© Mayo Foundation)

Before & After Bronchodilator Studies

- Indication
  - FEV_1% < is less than 70%.
  - A new medication is being evaluated.
  - Patient is known to have asthma or COPD.
- Medications should be withheld.
  - β_2 agonist: see CPGs
  - Methylxanthines 12 hours
  - Cromolyn Sodium 8-12 hours
  - Inhaled Steroids: maintain dosage
  - Anticholinergics 8 hours

Before & After Bronchodilator Studies

- Some patients may be unable to withhold medication
  - Document in interpretation section
- After administering the bronchodilator, wait 15 minutes before starting the post test
- If atropine is given, wait 45 – 60 min
- FEV_1 is most commonly used to quantify response

Bronchodilator Mechanics

- Pre- & Post-bronchodilator PFT
  - Some disagreement (ATS, ITS, ACCP)
  - ATS:
    - 12 % improvement and 200 mL in FVC OR
    - 12 % improvement and 200 mL in FEV_1
- % change = $\frac{\text{Post } FEV_1 - \text{Pre } FEV_1}{\text{Pre } FEV_1} \times 100$

Pre/Post Example

		PATIENT A		PATIENT B	
	Predicted	Before	After	Before	After
FVC (L)	4.70	2.93 (62)	3.46 (74) 23%	2.93 (62)	2.95 (63)
FEV_1 (L)	3.56	1.29 (34)	1.59 (45) 300 mL	2.63 (74)	2.69 (76)
FEV_1/FVC (%)	76	44	46	90	91

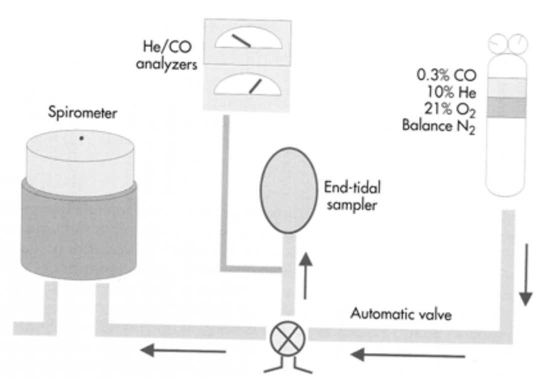
Before & After Bronchodilator Studies

- Avoid using the $FEF_{25-75\%}$ because it is heavily dependent on FVC.
- Common to see improvements in FEV_1 but no improvement in $FEF_{25-75\%}$.
- If FEF $_{25-75\%}$ is used to determine response it should be isovolume corrected for changes in FVC.

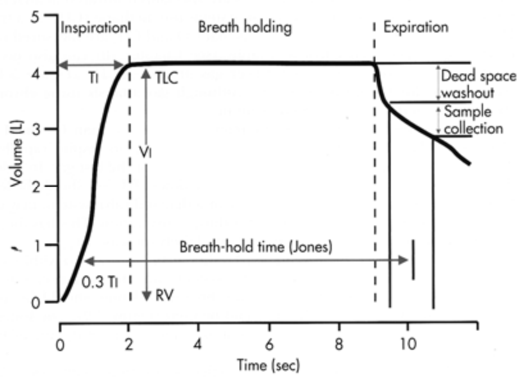
DIFFUSING CAPACITY

- Evaluates the ability of a test gas to get across the alveolar-capillary membrane.
- DL_{CO} is a measurement of diffusion in the lungs.
- Predicted based on Height, Age, & Sex or Age, Sex, and BSA. Normal value is 25 ml CO/min/mmHg (STPD)
- Multiple methods of testing
  - Single Breath (breath hold) is the most common.
- Gas diffusion across the A-C membrane is determined by:
  - Diffusion coefficient of the gas used (CO is best)
    - Patient should not have smoked for at least 24 hours.
  - Surface area of the membrane (DL/VA)
  - Thickness of the membrane
  - Blood volume and flow in the pulmonary capillary tree
  - Distribution of the inspired gas/blood flow (body position)
  - Hemoglobin or Hematocrit (correct for Hb level)

DLCO Testing Equipment

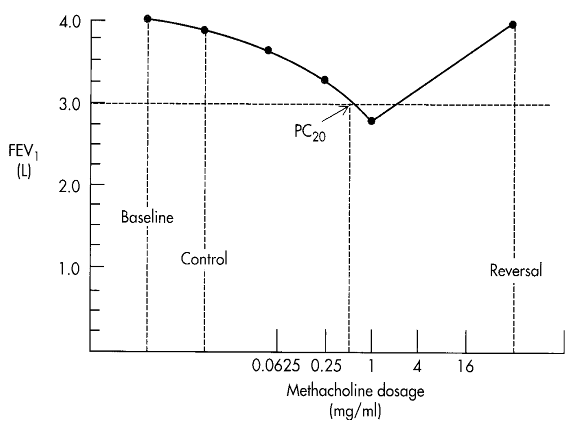


DLco Curve



BRONCHIAL PROVOCATION

- **Used to identify and characterize airway hyperresponsiveness.**
- **Used when patient has symptoms of bronchospasm with normal PFTs or uncertain post-bronchodilator results.**
- **Several provocative agents used:**
  - **Methacholine (most common)**
  - **Histamine**
  - **Cold air**
  - **Exercise**
- **Nebulizer output and/or use of a dosimeter.**
- **Response quantified with spirometry (FEV_1, FVC, FEV_1/FVC%).**
  - **PC_{20}**
- **Need for increased monitoring secondary to bronchospasm.**

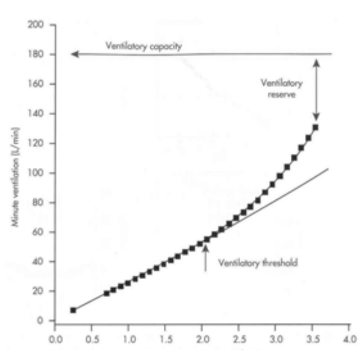


EXERCISE TESTING

- **Allows for evaluation of the heart and lungs under conditions of increase metabolic demand.**
- **Cardiopulmonary variables (V_E; V_t, f, VO_2, VCO_2, RER [~RQ], Anaerobic Threshold) are assessed in relation to increasing workload (treadmill or exercise bike).**
- **Three types of tests:**
  - **Testing to evaluate the exercise tolerance**
  - **Testing to evaluate desaturation using oximetry**
  - **Testing to evaluate exercise-induced bronchospasm.**

ANAEROBIC THRESHOLD (AT)

Anaerobic Threshold (Ventilatory Threshold) occurs when the energy demands of the exercising muscles exceed the body's ability to produce energy by aerobic metabolism.



Measurement of Respiratory Muscle Strength

- **Maximum Inspiratory Pressure (MIP or NIF)**
- **Maximum Expiratory Pressure (MEP)**
- **Forced Vital Capacity**
- **MVV**

MIP or NIF

- This is the lowest pressure developed during a forceful inspiration against an occluded airway.
- It is measured at RV or FRC and recorded as a negative number in cm H_20 or mm Hg.
- A small leak is introduced between the occlusion and the patient's mouth.
  - This eliminates pressures generated by the cheek muscles, but does not significantly affect readings.

MIP or NIF

- Is used to assess:
  - Response to respiratory muscle training.
  - Muscle strength during weaning from MV.
- Record at least 3 efforts.
- Pressure plateau of 1 to 3 seconds.
- Maximal value should be recorded.
- Two best efforts should be reproducible within 10% or 10 cm H_20.

MIP or NIF

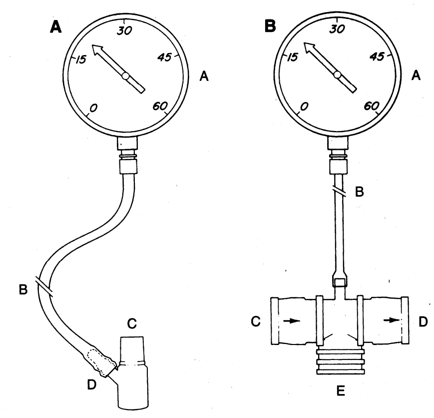
- Normal values for adult should be greater than –60 cm H_2O.
- Measures *inspiratory* muscle strength.
- Decreased values seen in
  - Neuromuscular diseases
  - Hyperinflation of the lungs
  - Chest wall or spinal deformities (scoliosis)
  - Stroke
- Value below – 20 cmH_2O is indication for mechanical ventilation.

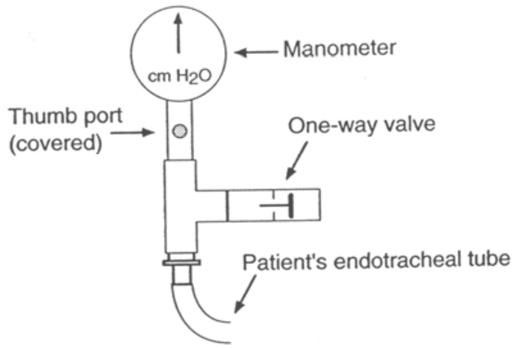
Maximal Expiratory Pressure

- Highest pressure that can be developed during a forceful expiration against an occluded airway.
  - Usually measured at TLC.
- It is reported as a positive number in cm H_20 or mm Hg.
- A small leak is introduced between the occlusion and the patient's mouth.

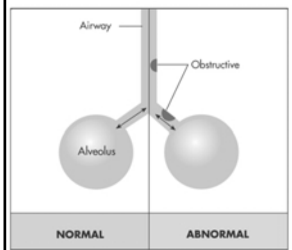
MEP

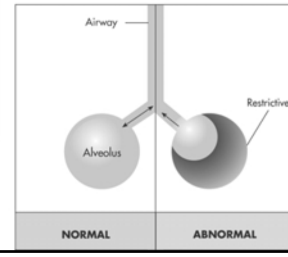
- Healthy adults can generate a MEP over 100 cm H20
- Is used to assess *expiratory muscle strength* and the ability of the patient to *cough.*
- Decreased values seen with:
  - Expiratory muscle weakness
  - Neuromuscular disease
  - High cervical spine fractures
  - Damage to nerves controlling the abdominal and accessory muscles
  - Obstructive lung disease





Differential Diagnosis





Obstructive Disease

- **An obstructive ventilatory defect may be defined as a disproportionate reduction of maximal airflow from the lung with respect to the maximal volume (VC) that can be displaced from the lung. (ATS)**
  - **Airflow limitation**
  - **Airway narrowing during expiration**
  - **Airway Resistance problem**
  - **Evaluate the FEV_1, FVC, and FEV_1/FVC.**

Obstructive Diseases

- **Obstructive Lung Diseases**
  - **Cystic Fibrosis**
  - **Bronchiectasis**
  - **Asthma**
  - **Chronic Bronchitis**
  - **Emphysema**

Obstructive Airway Diseases

- **Lung Tumors/Neoplasm**
- **Foreign Bodies**
- **Goiters**
- **Vocal Cord Dysfunction**
- **Croup/Epiglottitis**

Causes of Increased Airway Resistance

- **Chronic inflammation and swelling**
- **Excessive mucus production and accumulation**
- **Tumor projecting into a bronchus**
- **Destruction and weakening of the distal airways**
- **Bronchial smooth muscle constriction**

Dynamic Compression

- Effort-dependent portion of FVC
  - First 20-30 % of volume exhaled
  - Peak flow
  - Muscular effort of individual
- Effort-independent portion of FVC
  - Last 70-80 % of volume exhaled
  - Slope of Flow-Volume loop
  - Limited by dynamic compression of the airways
  - Equal Pressure Point

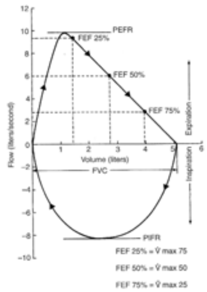
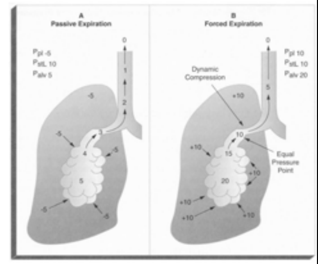


Fig. 3-8 Flow-volume loop.

Equal Pressure Point

- Pressure outside the airway equals pressure inside the airway at the EPP.
- When pressure outside exceeds that inside (as occurs during a forced exhalation), the airway collapses and flow stops.



Obstructive Disease Severity

VC	FEV_1/FVC	% Pred FEV_1	Severity
N	N		WNL
-	L	≥ 100 %	Physiological Variant
-	L	<100 & ≥ 70%	"Mild"
-	L	<70 & ≥ 60%	"Moderate"
-	L	<60 & ≥ 50%	"Moderately Severe"
-	L	<50 & ≥ 34%	"Severe"
-	L	<34%	"Very Severe"

Table 8 - Therapy at Each Stage of COPD

Old	0: At Risk	I: Mild	II: Moderate IIA	II: Moderate IIB	III: Severe
New	0: At Risk	I: Mild	II: Moderate	III: Severe	IV: Very Severe
Characteristics	• Chronic symptoms • Exposure to risk factors • Normal spirometry	• FEV_1/FVC < 70% • FEV_1 ≥ 80% • With or without symptoms	• FEV_1/FVC < 70% • 50% ≤ FEV_1 < 80% • With or without symptoms	• FEV_1/FVC < 70% • 30% ≤ FEV_1 < 50% • With or without symptoms	• FEV_1/FVC < 70% • FEV_1 < 30% or FEV_1 < 50% predicted plus chronic respiratory failure
	Avoidance of risk factor(s); influenza vaccination				
		Add short-acting bronchodilator when needed			
			Add regular treatment with one or more long-acting bronchodilators *Add* rehabilitation		
				Add inhaled glucocorticosteroids if repeated exacerbations	
					Add long-term oxygen if chronic respiratory failure *Consider* surgical treatments

Restrictive Disease

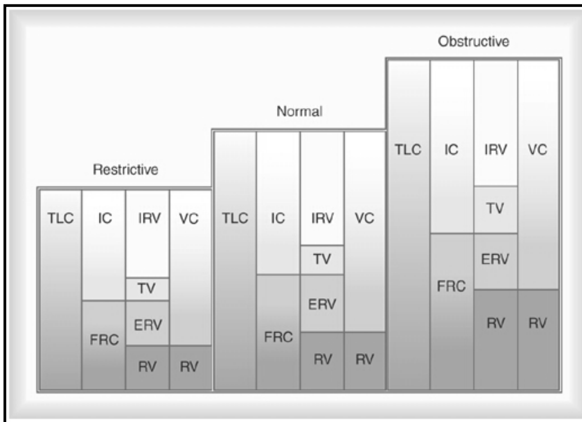
- A restrictive ventilatory defect is characterized physiologically by a reduction in TLC. (ATS)
  - Lung Parenchyma or Thoracic Pump defect
  - Problem getting air in
  - Lung/Thoracic Compliance problem
  - Evaluate lung volumes (TLC, RV, RV/TLC)

Restrictive Lung Diseases

- Interstitial Lung Diseases
  - Pneumoconiosis
  - Sarcoidosis
  - Idiopathic pulmonary fibrosis
- Diseases of the chest wall and pleura
  - Pleurisy
  - Kyphoscoliosis/Scoliosis
  - Pleural effusions
  - Obesity
  - Pneumothorax

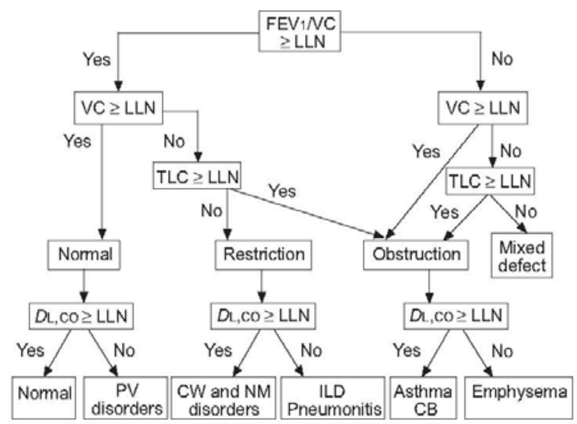
Restrictive Lungs Diseases

- **Neuromuscular Disorders**
  - **Guillian-Barre**
  - **Myasthenia Gravis**
  - **ALS or Lou Gehrig's disease**
  - **Diaphragmatic paralysis**
- **CHF/Pulmonary Edema**

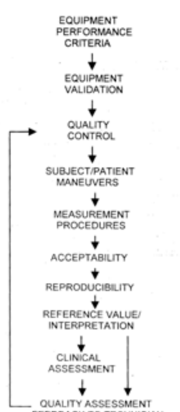


American Thoracic Society (ATS)

- **Criteria for PFT testing is based on recommendations of the** ATS
- **Standards have been published**
  - **1979 – Snowbird Spirometry Standards**
  - **1987 – Revised Standards**
  - **1991 – Reference values and Interpretation**
  - **1994 – Revised Standards**
    - **Selection of reference values**
    - **Spirometry performance**
    - **Set Quality Assurance Standards and have written a management and department procedure manual**
  - **2005 – ATS/ERS Task Force on Standardization of Testing and Interpretation**
  - **2007 – ATS/ERS Task Force on Spirometry in Children**



Steps in PFT Process



Quality Assurance

- **QA is a systematic approach to monitoring and evaluating the quality of the test and the test results**

Quality Assurance

- **Pre-testing**
  - **Demographics, History, Medications, Pre-test instructions, appropriate order, calibration of equip.**
  - **Competency of PFT personnel/Training**
  - **Instrumentation/Equipment**
- **Testing**
  - **Patient comprehension of instructions and expectations**
  - **Technologists instructions & training**
  - **Reference equations**
  - **Patient performance**
- **Post-Testing**
  - **Maneuver selection**
  - **Interpretation/comments; Report Review**

Spirometers

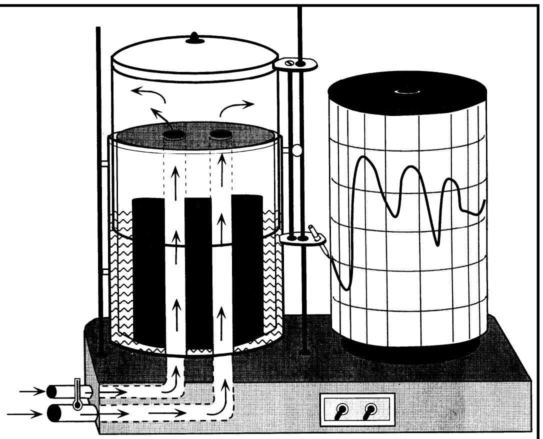
- **Volume Displacing Spirometers**
- **Flow Sensing Spirometers**
  - **Pneumotachometers**

Volume Displacing Spirometers

- **Water Seal Spirometer (Collins or Stead-Wells)**
  - ***"Gold Standard"* – most accurate**
  - **Uses a** Kymograph **as a recording device**
  - **Best system to check accuracy of other PFT equipment**
- **Dry Rolling Seal**
- **Bellows Type**
- **Diaphragm**

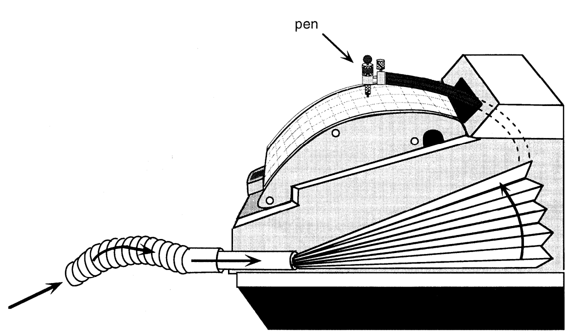
Volume Displacing Spirometers

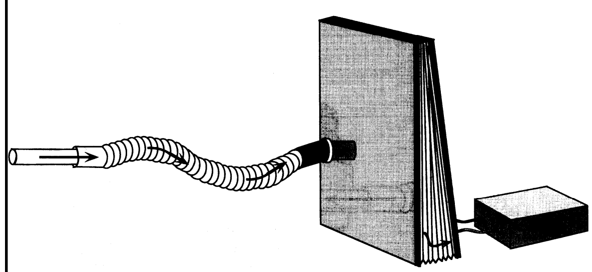
- **Advantages**
  - **Directly measure volume**
  - **Low cost**
  - **Ease of operation**
- **Disadvantages**
  - LEAKS
  - **Large and bulky (little portability)**
  - **Water in water seal needs changing**
  - **Without a microprocessor/computer, manual calculations are needed**

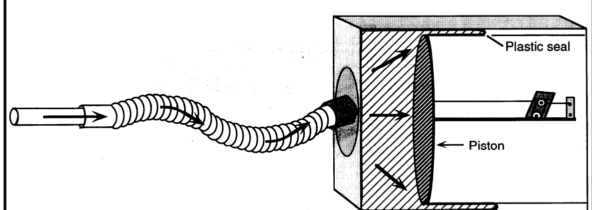


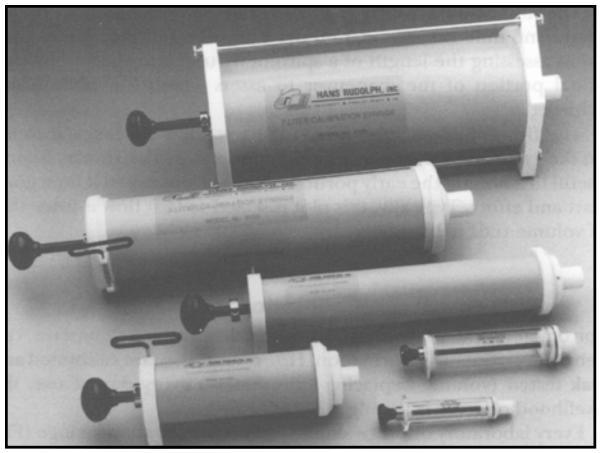
QA for Water Seal Spirometers

- **Water level checked daily**
- **Paper tracing speed checked daily**
  - **Paper speed 32, 160 & 1920 mm/min**
- **Leak test & calibration checked daily**
- **Water changed weekly**

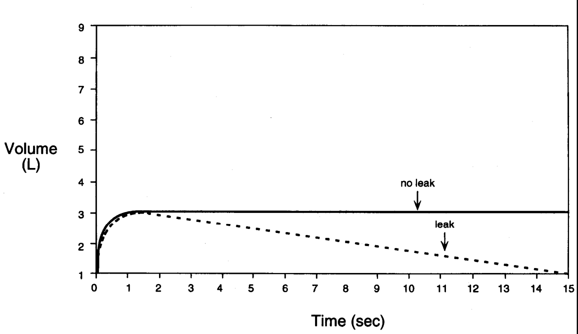








SPIROMETER LEAK TEST



Flow Sensing Spirometers

- **Use of various physical principles to produce a signal proportional to gas flow**
- **Integration is a process in which flow (V/T) is divided into a large number of small intervals of time and volume is calculated**
  - **Flow = <u>Volume</u> Volume = Flow x Time**
    Time

Uses of Flow Sensing Spirometers

- **Respirometers**
- **Mechanical Ventilators**
- **Incentive Spirometers**
- **PFT equipment**
- **Exercise Equipment**
- **Metabolic Measurement Carts (Indirect Calorimetry)**

Types of Flow Sensing Spirometers

- **Pneumotachometers**
- **Turbine or Turbinometers**
- **Heated Wire Flow Sensors**
- **Sonic Devices (Sound waves)**
  - **Ultrasonic**
  - **Vortex**

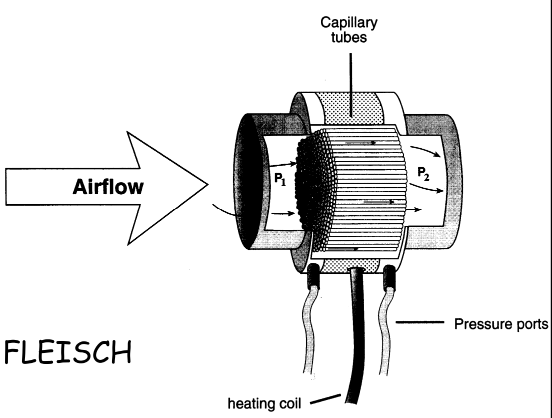
Flow Sensing Spirometers

- **Pneumotachometers**
  - **Pressure Differential Flow Sensors**
  - **Uses a pressure change caused by a resistive element to calculate flow**
  - **Flow = Δ Pressure (any change in P will affect flow)**

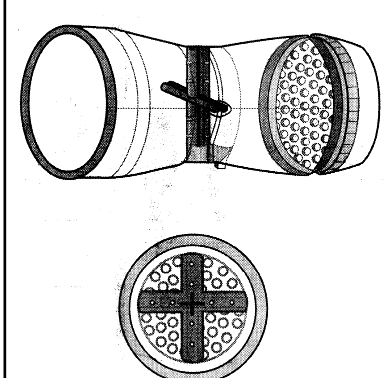
    Resistance (keep resistance the same)

Types of Pneumotachs

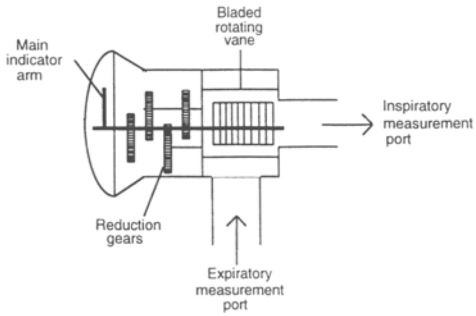
- **Fleisch Type (bundle of capillary tubes)**
- **Screen Type (fiber or metal)**
- **Ceramic Type**
- **Variable & Fixed Orifice**

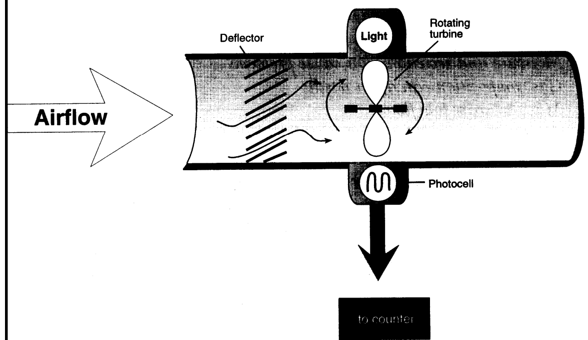


FLEISCH

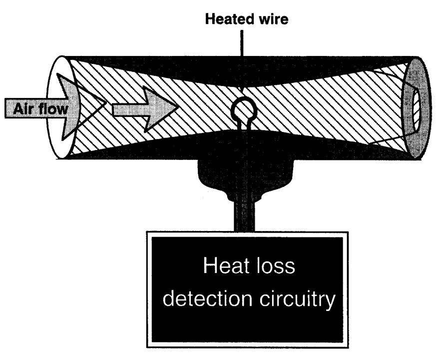


Turbine Device: Wright Respirometer

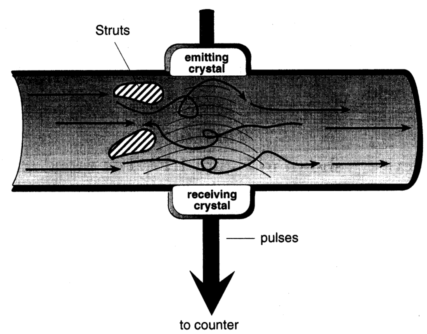




Hot wire Anemometer



Vortex-Shedding Device



Flow Sensing Spirometers

- **Advantages**
  - **Smaller and usually more portable**
  - **Computerized; no manual calculations**
  - **Bidirectional devices provide flow volume loop capabilities**
  - **Can be used to continuously measure minute ventilation**

Flow Sensing Spirometers

- **Disadvantages**
  - **More knowledge needed to operate**
  - **Frequent calibration**
  - **Moisture/secretions can affect results**
  - **Gas composition can affect results**
  - **May not be accurate at very high or low flowrates**

Flow Sensing Peak Flow Meters

- More important to be precise than accurate
- Repeated measurements should be reproducible (valid) within 5% or 10 L/min whichever is greater
- Tend to underestimate flowrate as altitude increases

Spirometer Calibration

- Spirometers should be calibrated every day
- Volume Spirometers should be leak tested
- A Super Syringe is used to calibrate spirometers.
  - +/-3% accuracy or 0.05L whichever is larger (diagnostic spirometer)
  - Use three flowrates 1 sec, 6 sec and between 1-6 sec
  - If using a 3 L super syringe, the volume measured by the device should be between 2.91 and 3.09 L

Spirometric Technique

Patient Preparation

- Explain which medications to stop taking before testing
- Instruct if physician wants patient to stop smoking before the test (DLCO)
- Explain to the patient the length of time
- Do not eat a full meal

Recommended Times for Withholding Bronchodilators

• Salmeterol	12 hours
• Ipratropium	6 hours
• Terbutaline	4-8 hours
• Albuterol	4-6 hours
• Metaproterenol	4 hours
• Isoetharine	3 hours

Patient Preparation

- Pulmonary history/physical assessment
  - Height, Weight, Age, Race, Sex
  - Patients who cannot stand use arm span to determine height
  - Height should be measured without shoes
- Predicted normal values are based on
  - Height
  - Age
  - Sex
  - Race (?)

Patient Preparation

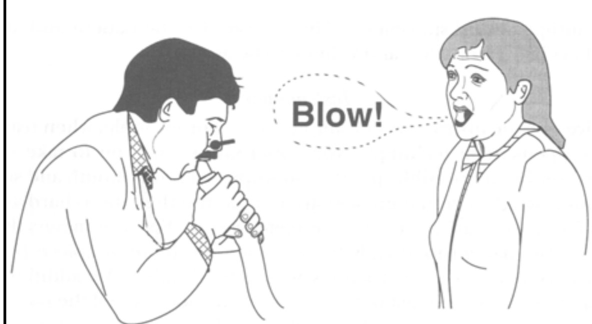
- Determine any relative contraindications
  - Hemoptysis
  - Pneumothorax
  - Unstable cardiovascular status
  - Thoracic/abdominal or cerebral aneurysms
  - Recent eye surgery
  - Acute symptoms (vomiting, nausea, dizziness)
  - Recent surgery of thorax or abdomen
  - Should not do after a full meal

Patient Preparation

- Keep explanations simple
- Explain that the test does not hurt but requires "*lots of effort*"
- Explain that each test may require a number of efforts
- Position the patient
  - Chin up, feet flat on the floor, loosen clothing

Patient Preparation

- Explain & demonstrate the maneuver
  - Explain the procedure and what you expect from the patient
  - Stop oxygen just for test maneuvers
  - Demonstrate the maneuver
  - Coach the patient throughout the manuever
- Evaluate for proper performance and carefully inspect the graphs



ATS Standards

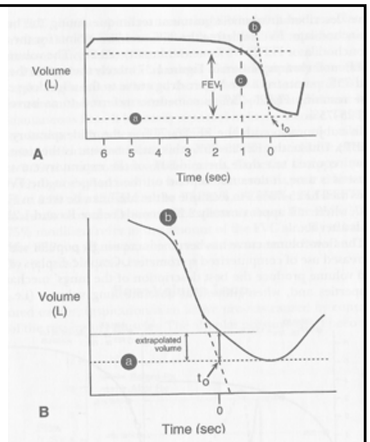
- 3 Acceptable FVC Maneuvers
  - If an acceptable maneuver cannot be obtained after 8 attempts, testing may be discontinued
- 2 Trials that are reproducible (valid)
  - The two largest FVC from acceptable trials should not vary by more than 0.15 L
  - The two largest FEV_1 from acceptable trials should not vary by more than 0.15 L

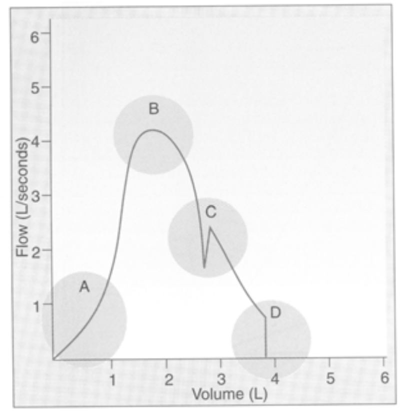
Can be 100 mL if the FVC is less than or equal to 1.0 L

Acceptability Criteria

- Good start of the test
  - No hesitation.
  - An extrapolated volume of $\leq$ 5% of the FVC or 150 mL, whichever is greater.
- Good Effort
- No coughing (especially during the 1st sec)
- No variable flows
- No early termination
  - Minimum exhalation of 6 seconds unless there is a plateau

Back Extrapolated Volume





Maneuver acceptability

Message	Criterion
Don't hesitate	back extrapolated volume > 150 mL
Blast out faster	time to peak expiratory flow > 120 ms
Blow out longer	change in exhaled volume during the last 0.5 s > 100 mL, and expiratory time < 2 s (see also here)
Blast out harder	PEF values do not match within 1.0 L/s,
Deeper breath	FVC values do not match within 150 mL
	Only one error message is displayed (in the order of priority listed above)
Good test session	After 2 acceptable maneuvers that match

Quality control grades

A	at least two acceptable maneuvers with the largest two FEV_1 v matching within 100 mL
B	at least two acceptable maneuvers with FEV_1 values matching 101 and 150 mL
C	at least two acceptable maneuvers with FEV_1 values matching 151 and 200 mL
D	only one acceptable maneuver, or more than one, but the FEV match > 200 mL (with no interpretation)
F	no acceptable maneuvers (with no interpretation)

Spirometry Induced Bronchospasm

- **Every test shows deteriorating flowrates**

- **All tests must be reported at BTPS**
- **All predicted values are based on**
  - **Age**
  - **Height**
  - **Sex**
  - **Race (?)**
- **Weight is reported, but not used in prediction**

Office/Bedside Spirometry

- **FEV_6 can replace FVC as an end of test criteria**
  - **Shortens the testing session**
  - **Avoids overexertion while attempting a FVC**
  - **Airway obstruction will be detected when FEV_1/FEV_6 are below the lower limit of normal**

APPENDIX 4: Selected Adult Reference Populations, Methods, and Regression Equations for Spirometry and Lung Volumes

Table A4.1 FVC (L)

Reference	Year	Race[a]	Age Range	No. Subjects	Sex	Method[b]	Site	Regression Equation
Abramowitz	1965	B	20–54	51	M	WS	New Jersey	0.051(Hcm) − 0.018(A) − 3.82
Coultas	1988	H	25–80	80	M	WS	New Mexico	4.959(Hm) − 0.028(A) − 2.88
Cherniack	1972	W	15–79	870	M	B	Canada	0.121(Hin) − 0.0136(A) − 3.184
Crapo	1981	W	15–91	125	M	WS	Utah	0.06(Hcm) − 0.0214(A) − 4.65
Crapo	1990	H	25–75	116	M	RS	Utah, California	0.0562(Hcm) − 0.0313(A) − 3.7883
DaCosta	1971	A	20–66	134	M	WS	Singapore	0.041(Hcm) − 0.0105(A) − 2.76
Enright	1993	W	65–85	245	M	WS	USA	0.0567(Hcm) − 0.0206(A) − 4.37
Knudson	1983	W	25–85	86	M	P	Arizona	0.0844 (Hcm) − 0.0298(A) − 8.7818
Morris	1971	W	20–84	517	M	WS	Oregon	0.148(Hin) − 0.025(A) − 4.241
Mustafa	1977	B	15–74	623	M	B	Africa	0.0604 (Hcm) − 0.016(A) − 6.14
Roberts	1991	W	18–86	83	M	P	London	6.628(Hm) − 0.028(A) − 5.377

Table 2 - Classification of Severity*

Stage	Characteristics
0: At Risk	• normal spirometry • chronic symptoms (cough, sputum production)
I: Mild COPD	• $FEV_1/FVC < 70\%$ • $FEV_1 \geq 80\%$ predicted • with or without chronic symptoms (cough, sputum production)
II: Moderate COPD	• $FEV_1/FVC < 70\%$ • $50\% \leq FEV_1 < 80\%$ predicted • with or without chronic symptoms (cough, sputum production)
III: Severe COPD	• $FEV_1/FVC < 70\%$ • $30\% \leq FEV_1 < 50\%$ predicted with or without chronic symptoms (cough, sputum production)
IV: Very Severe COPD	• $FEV_1/FVC < 70\%$ • $FEV_1 < 30\%$ predicted or $FEV_1 < 50\%$ predicted plus chronic respiratory failure