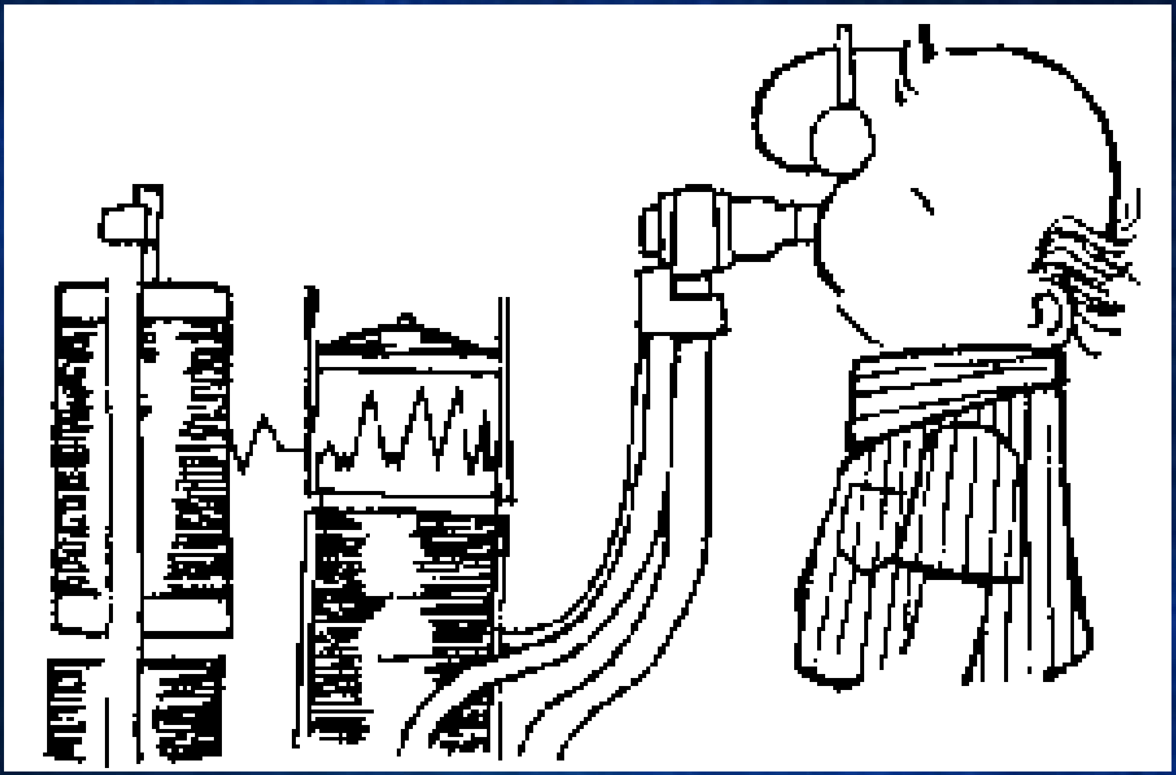
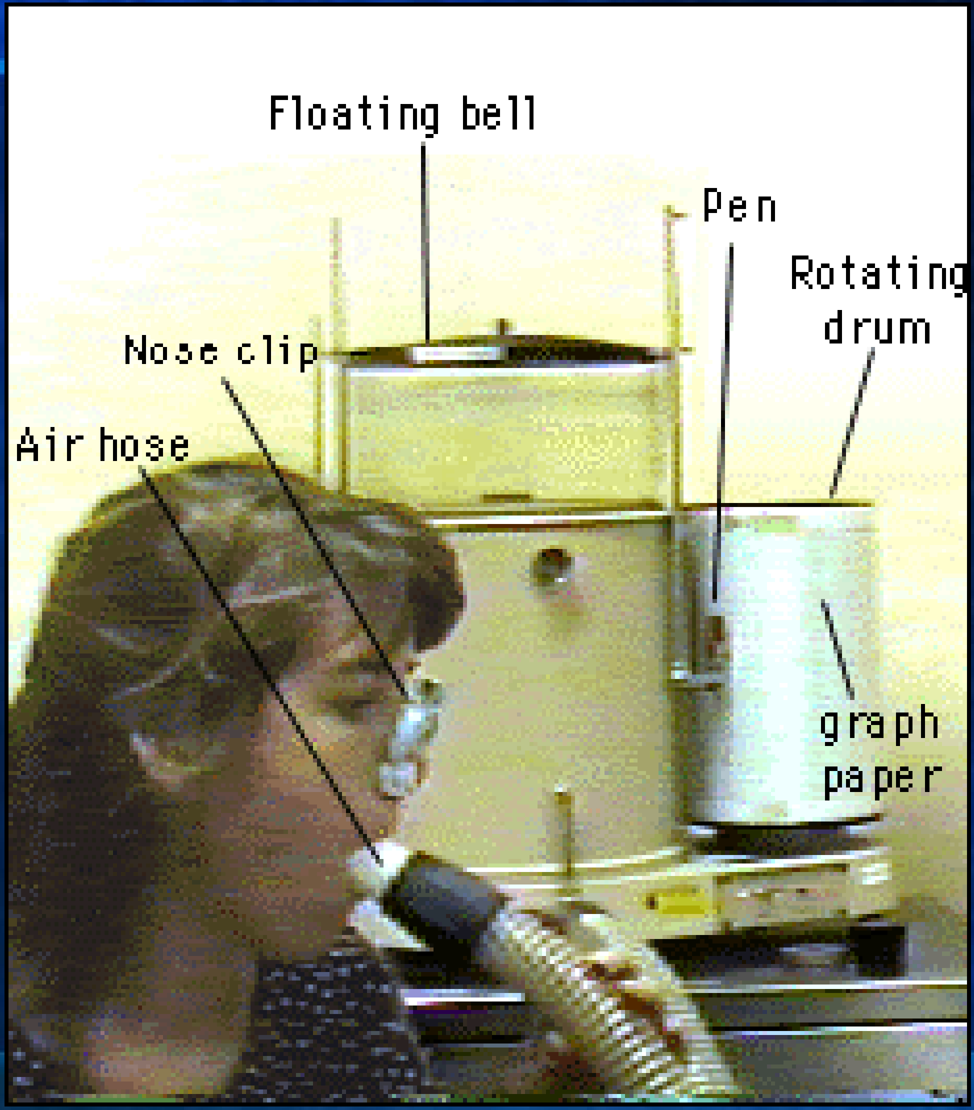
Pulmonary Function Tests

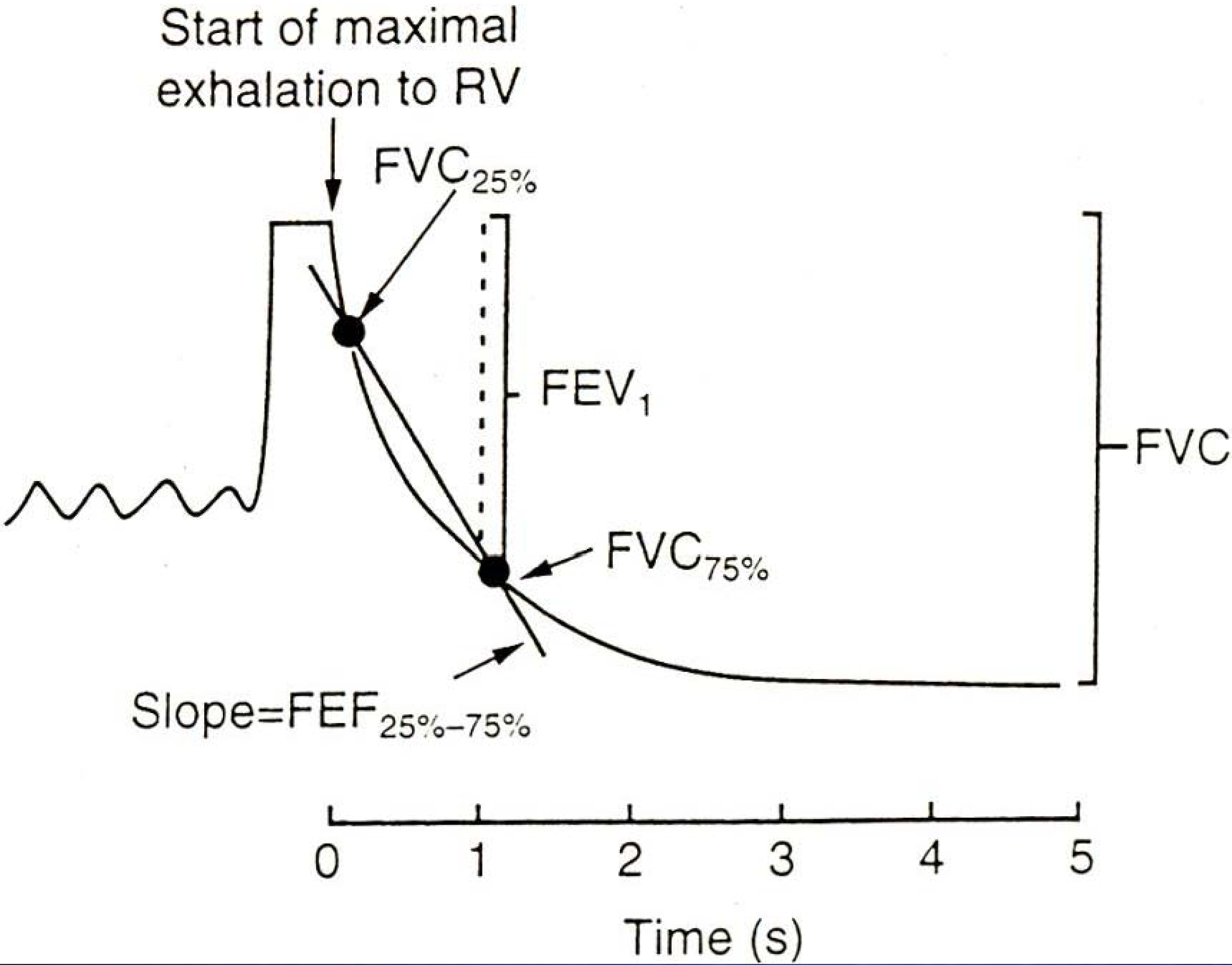


Three Types of Pulmonary Function Tests

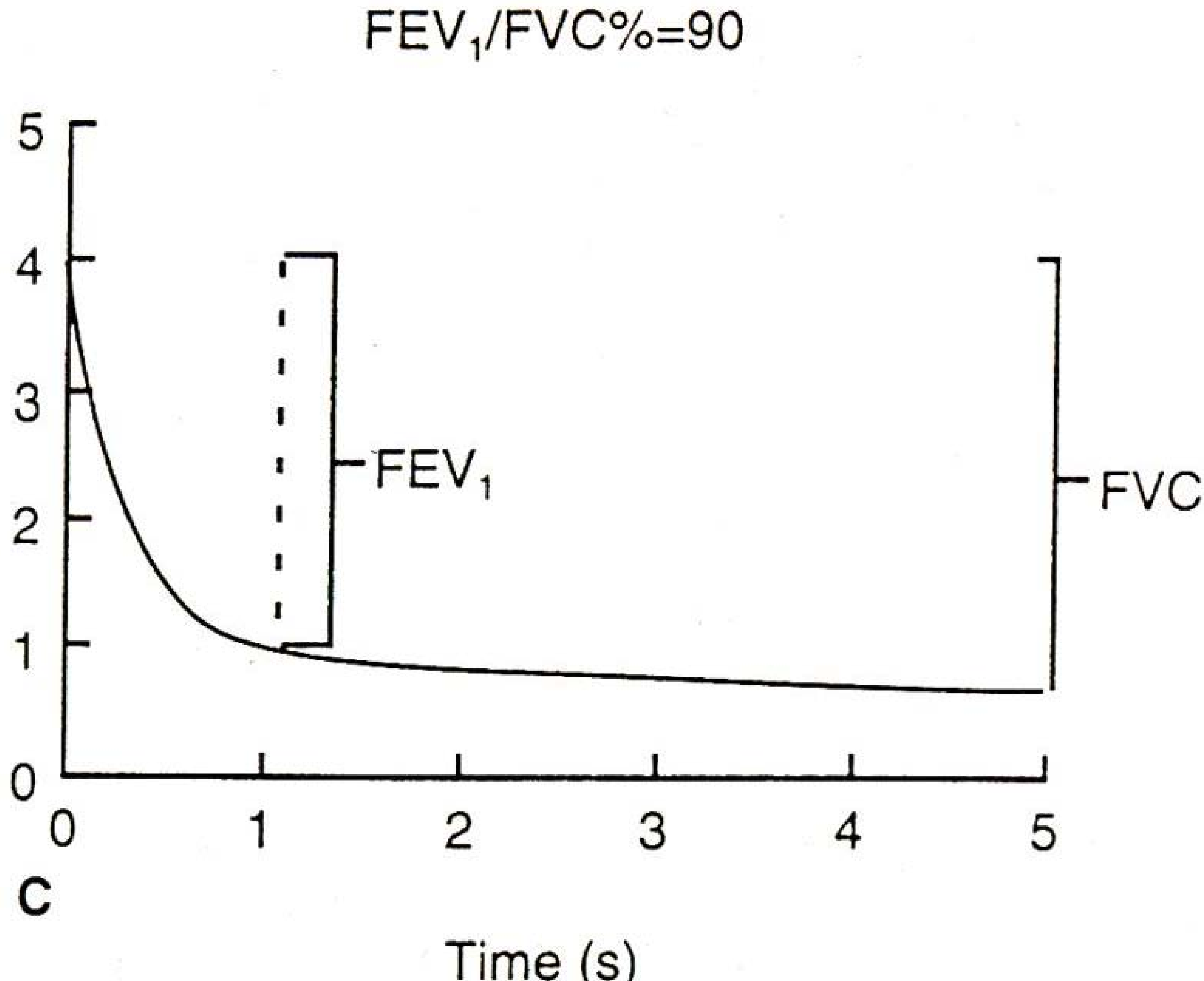
- Spirometry
  - Test of “dynamic function”
  - Helpful for “obstructive defects”
- Lung volume measurement
  - Test of “static function”
  - Helpful for “restrictive defects”
- Diffusion abnormalities
  - Helpful to assess gas exchange

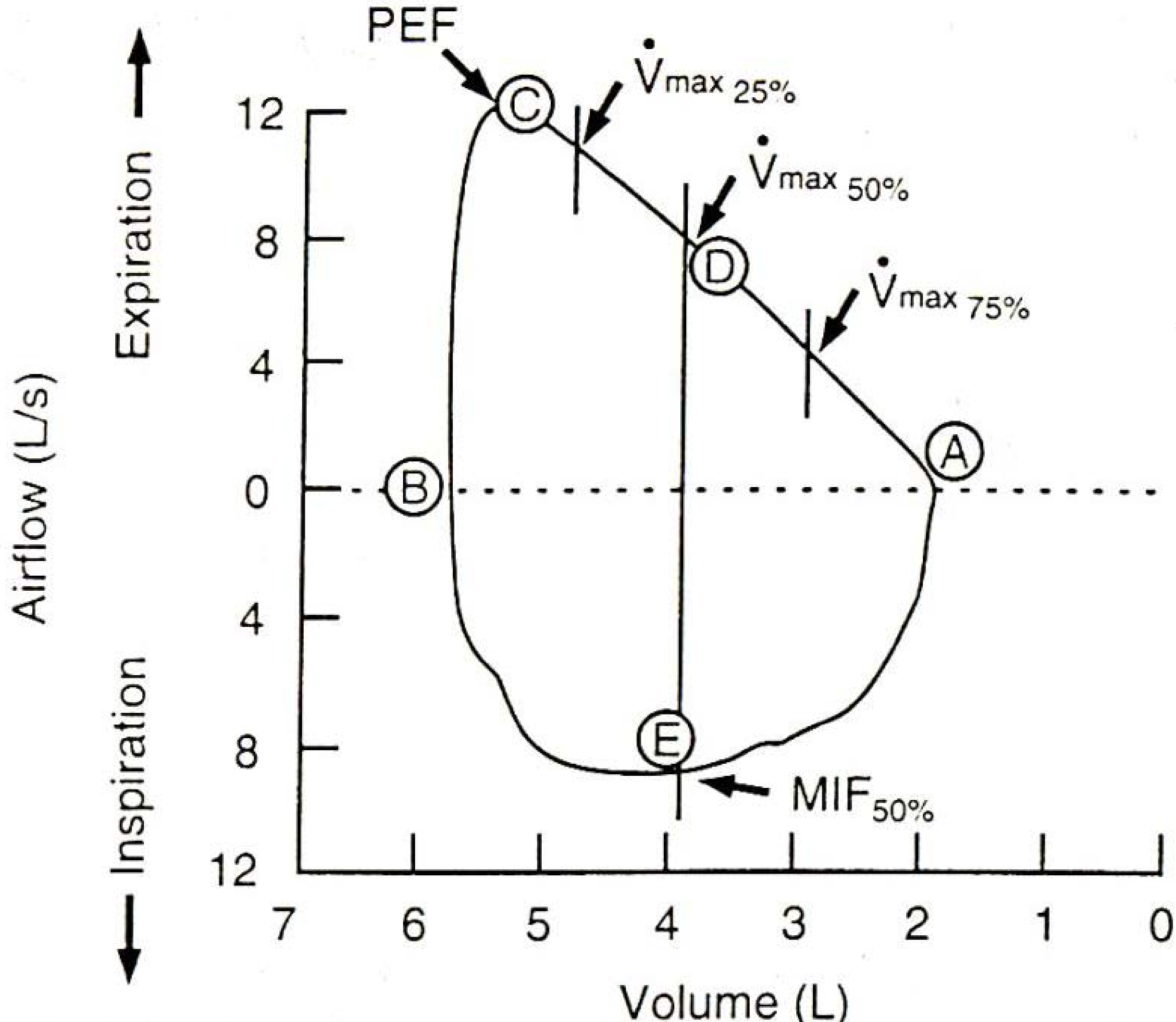
Spirometry

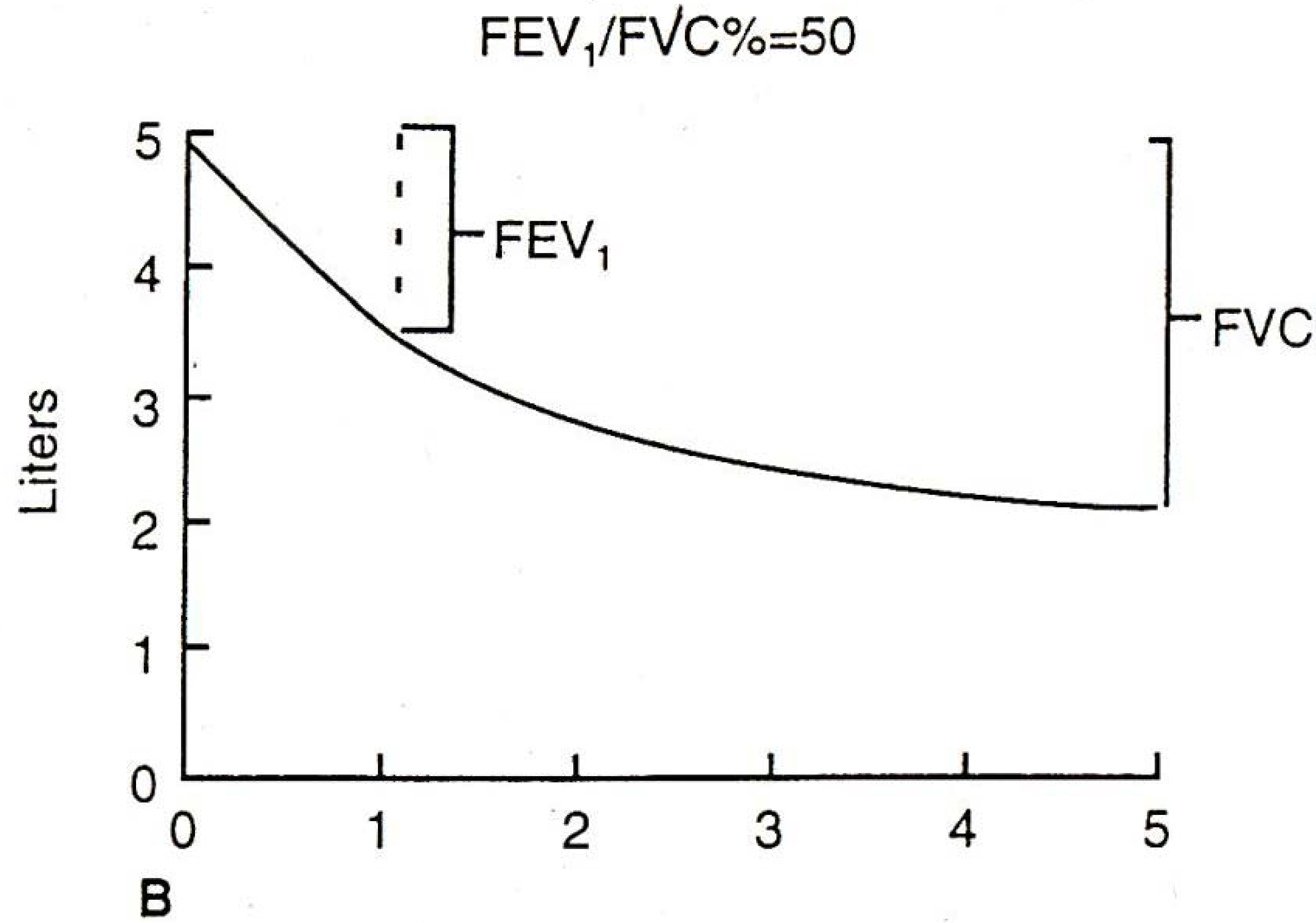

Floating bell
Pen
Rotating drum
Nose clip
Air hose
graph paper



Start of maximal exhalation to RV
$FVC_{25\%}$
FEV_1
FVC
$FVC_{75\%}$
Slope=$FEF_{25\%-75\%}$
0
1
2
3
4
5
Time (s)


FEV1/FVC%=90
5
4
3
2
1
0
0
1
2
3
4
5
FEV1
FVC
C
Time (s)

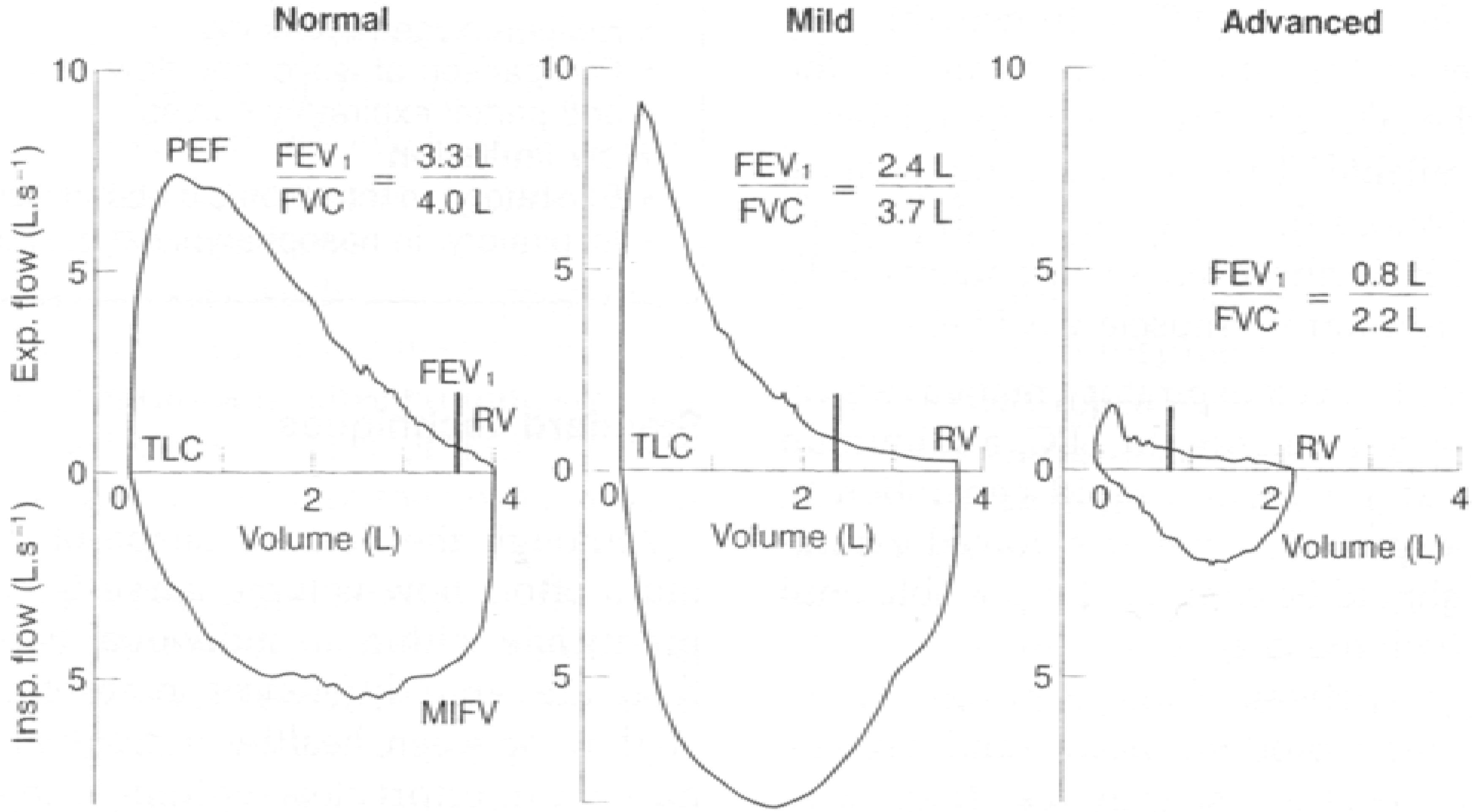

PEF
V̇max 25%
V̇max 50%
V̇max 75%
MIF50%
A
B
C
D
E
Expiration
Inspiration
Airflow (L/s)
12
8
4
0
4
8
12
7
6
5
4
3
2
1
0
Volume (L)


FEV1/FVC%=50
Liters
FEV1
FVC
0
1
2
3
4
5
B

PFTs: airflow obstruction

- Decrease in expiratory airflow and/or volume
- FEV_1 decreased
- FVC normal or decreased
- FEV_1/FVC decreased*
- FEF_{25-75} decreased

*definition of obstructive defect

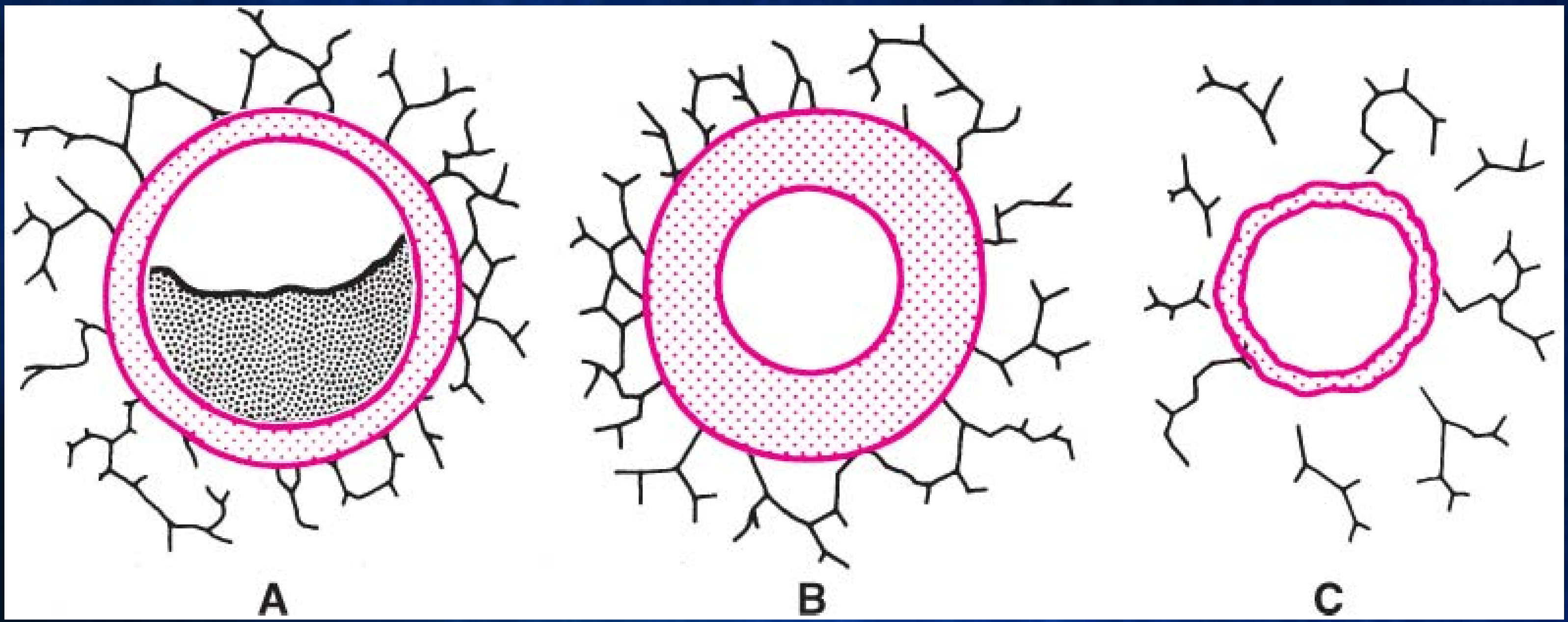


Normal
Mild
Advanced
Exp. flow (L.s⁻¹)
Insp. flow (L.s⁻¹)
PEF
FEV₁/FVC = 3.3 L/4.0 L
FEV₁
TLC
RV
MIFV
Volume (L)
FEV₁/FVC = 2.4 L/3.7 L
TLC
RV
Volume (L)
FEV₁/FVC = 0.8 L/2.2 L
RV
Volume (L)

Types of Airflow Obstruction

- Intraluminal obstruction
- Intramural obstruction
- Extraluminal obstruction
- Upper airway obstruction
- "Mixed"

Types of Airflow Obstruction

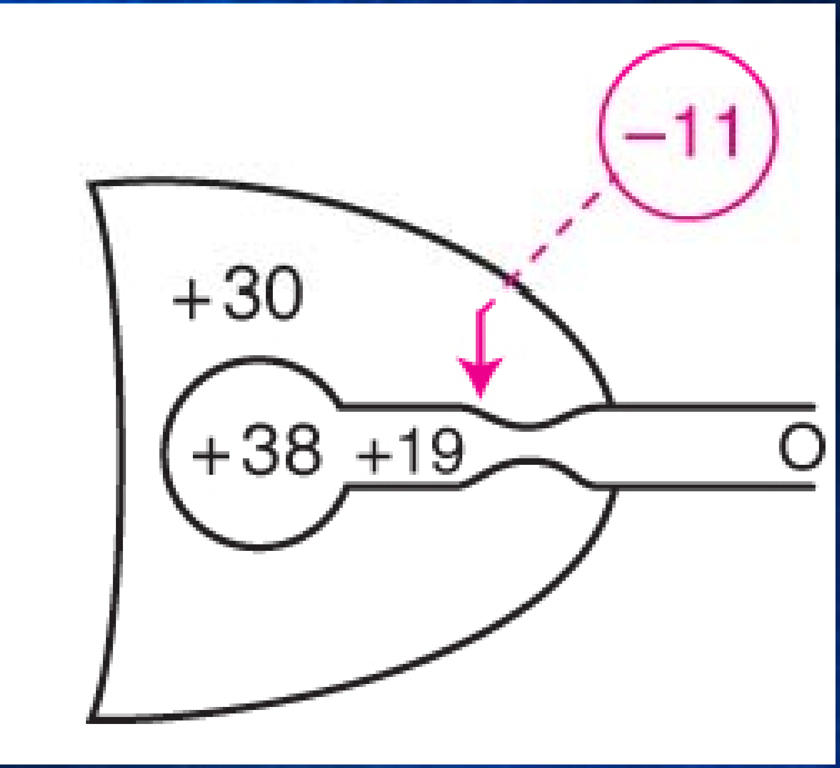


Intraluminal:
e.g., Secretions

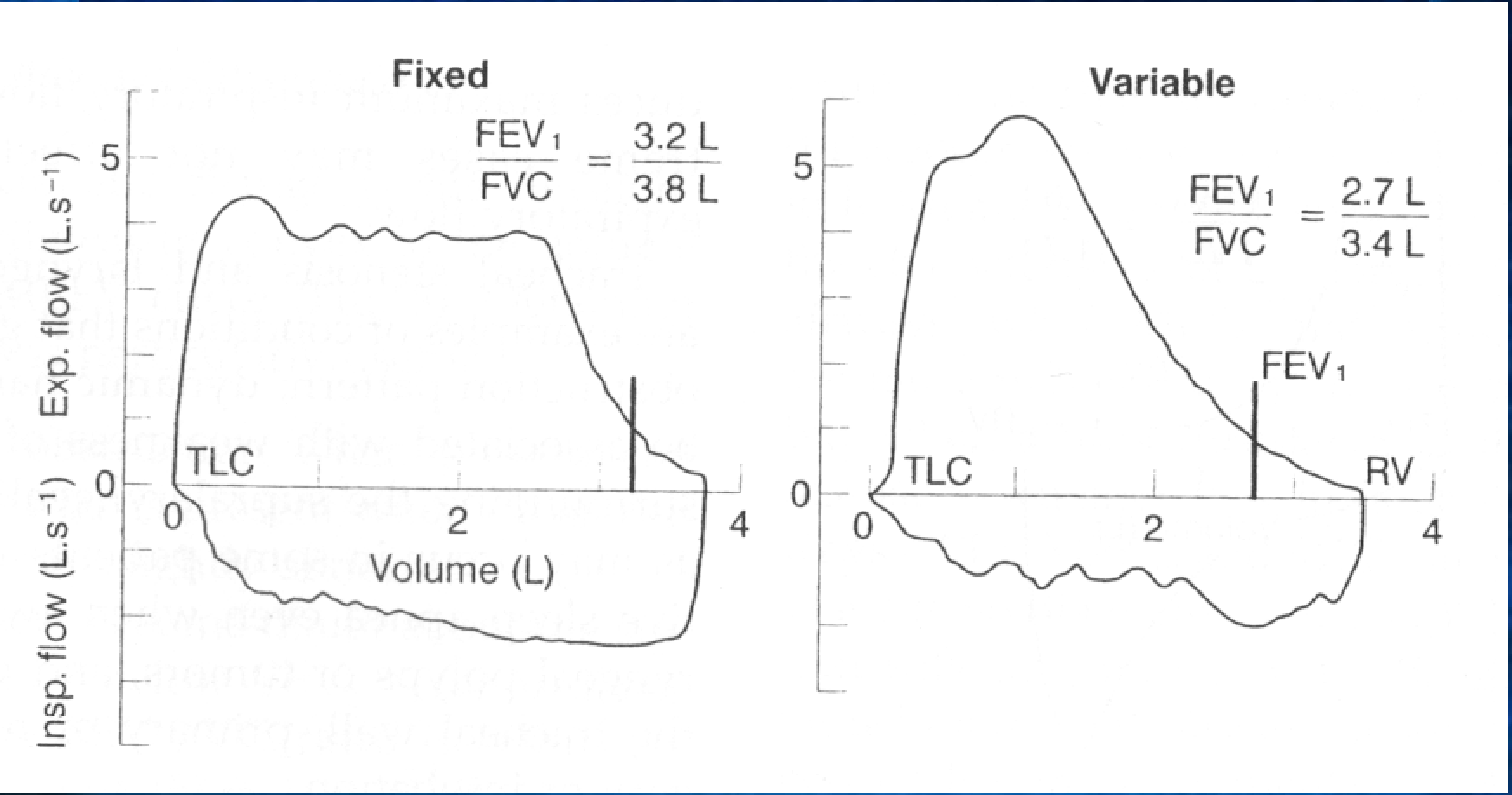
Intramural:
e.g., Edema

Extraluminal:
e.g., Loss of radial traction

Dynamic Airway Compression during Forced Expiration

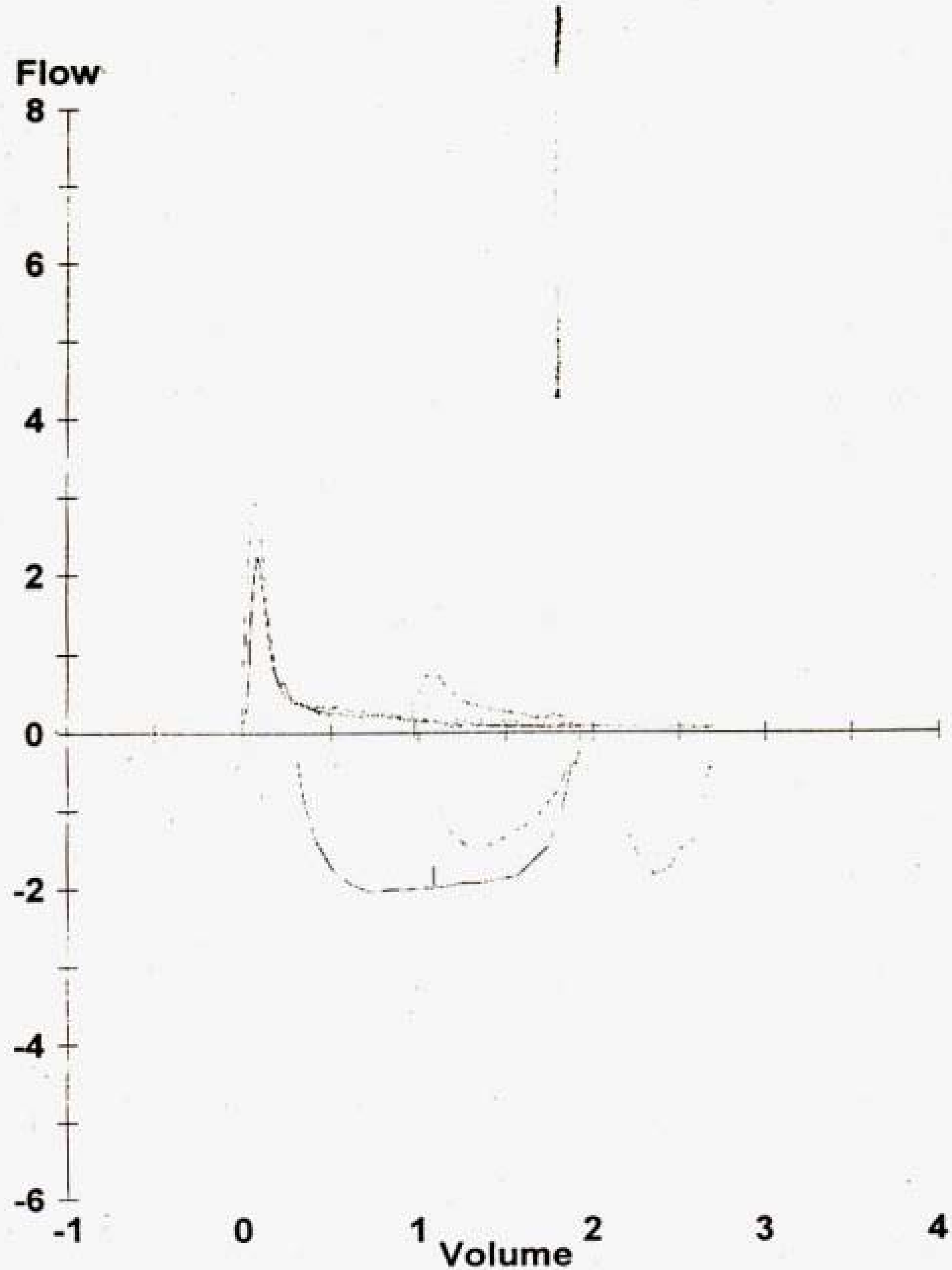


"Upper Airway" Obstruction



PFT Question #1

- FEV_1/FVC=obstructive ventilatory defect:
- Why is FEV_1 itself NOT diagnostic of an obstructive defect?



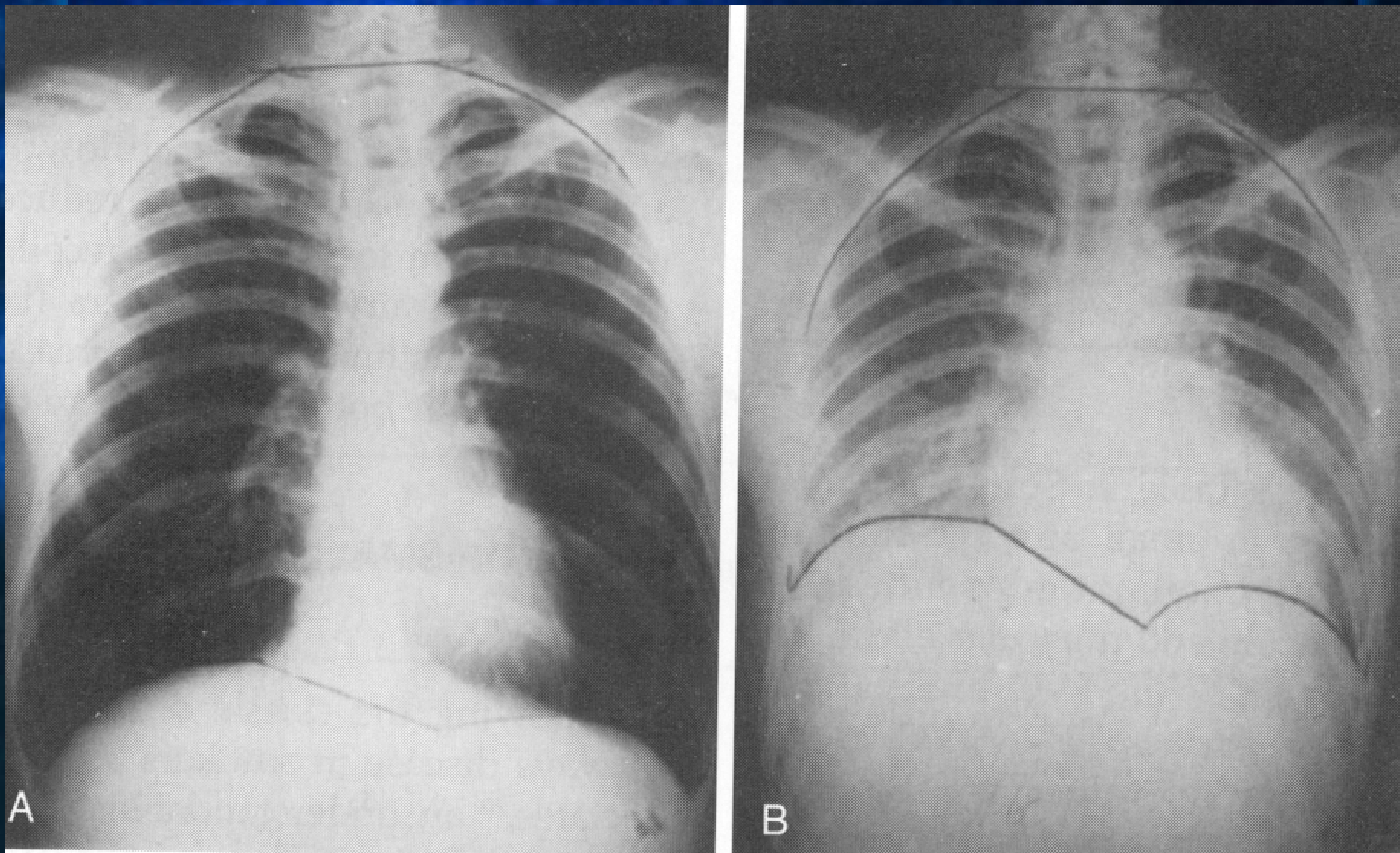
Flow
8
6
4
2
0
-2
-4
-6
-1
0
1
2
3
4
Volume

Patient: [redacted]
Age: 65 Gender: Male
Height(in): 70 (cm): 179
Weight(lb): 204 (kg): 92.5

Id: [redacted]
Location: Out-Pt Date: [redacted]
Temp: 29 PBar: 7(
Physician: [redacted]
Technician: GD

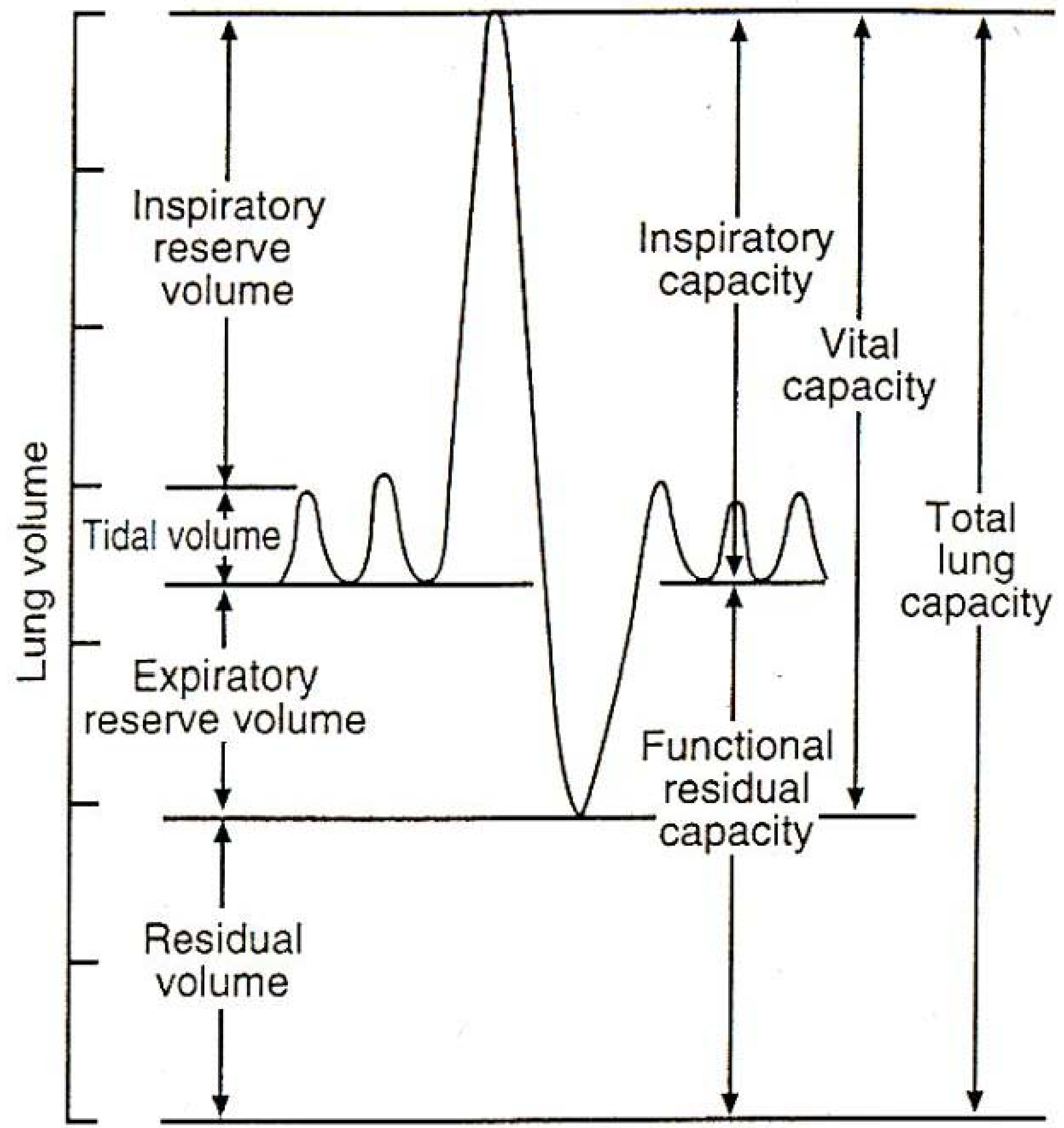
Spirometry		Ref	Pre Meas	Pre % Ref	Post Meas	Post % Ref
FVC	Liters	4.70	1.93	41	2.71	58
FEV1	Liters	3.63	0.54	15	0.60	17
FEV1/FVC	%	77	28		22	
FEF25-75%	L/sec	2.88	0.25	9	0.24	8
FEF25%	L/sec	7.80	0.27	3	0.29	4
FEF50%	L/sec	4.32	0.18	4	0.19	4
FEF75%	L/sec	1.57	0.10	6	0.09	6
PEF	L/sec	8.44	2.27	27	2.96	35
MVV	L/min	134			26	19
PIF	L/sec	3.67				
FIF50%	L/sec	4.59				
FET100%	Sec		13.02		19.70	

Lung Volumes		Ref	Pre Meas	Pre % Ref	Post Meas	Post % Ref
VC	Liters	4.49			2.85	63
TLC	Liters	6.59			8.66	132
RV	Liters	2.46			5.81	236
RV/TLC	%	39			67	
FRC PL	Liters	3.52			7.02	199
FRC He	Liters	3.52				
Vtg	Liters				6.94	


A
B

Lung Volumes

- “Static function”
- Gas Equilibration (“wash in” and “wash out”)
- Body plethysmography



Lung volume
Inspiratory reserve volume
Tidal volume
Expiratory reserve volume
Residual volume
Inspiratory capacity
Vital capacity
Total lung capacity
Functional residual capacity

Gas Equilibration Lung Volumes

- "Wash in:" Helium (insoluble gas) breathed from a reservoir of known VOLUME and CONCENTRATION, thus diluting its concentration by the volume of the lungs

$$V_{FRC} = V_{Reservoir} \text{x} \frac{C_{INIT} - C_{FINAL}}{C_{FINAL}}$$

Gas Equilibration Lung Volumes

- "Wash out:" Lung gas (N2) washed out during breathing of 100% O2
- Initial N2 concentration known (atmospheric); volume and N2 concentration of expired gas measured

$$V_{FRC} = V_{EXP} X \frac{C_{EXP}}{0.79 - C_{ALV(final)}}$$

Plethysmographic Lung Volumes

- Closed system at constant temperature
- Lungs and airway closed system when occluded
- Panting at FRC
- Inhalation → ↓ intrathoracic pressure, ↑ volume

Boyle's Law

$$P_1 V_1 = P_2 V_2$$

At constant temperature

$$P_{FRC} V_{FRC} = (P_{FRC} + \Delta P)(V_{FRC} + \Delta V)$$

Plethysmographic Lung Volumes

$$P_{FRC} V_{FRC} = (P_{FRC} + \Delta P)(V_{FRC} + \Delta V)$$

$$= P_{FRC} V_{FRC} + \Delta P V_{FRC} + P_{FRC} \Delta V + \Delta P \Delta V$$

$$0 = \Delta P V_{FRC} + P_{FRC} \Delta V + \Delta P \Delta V$$

Close to zero

$$\boxed{V_{FRC} = \frac{\Delta V}{\Delta P} P_{FRC}}$$

Plethysmographic Lung Volumes

- ΔP obtained from change in mouth pressure against occluded valve
- ΔV obtained from change in pressure in the plethysmograph as air in the box is compressed by increase in lung volume
- P_{FRC} =alveolar pressure=atmospheric pressure

PFTs: Restrictive ventilatory defect

- A decrease in lung expansion
- FEV_1 decreased
- FVC decreased
- FEV_1/FVC normal or increased
- Total Lung Capacity (TLC) decreased*

* Definition of restrictive ventilatory defect

PFT Questions #3 and #4

Why is FVC itself NOT diagnostic of a restrictive ventilatory defect?

Why is VC itself not diagnostic of a restrictive ventilatory defect?

Types of Restrictive Defects

- Parenchymal removal/destruction
- Parenchymal infiltration
- Extrapulmonary deformity
- Reduced force generation

Restrictive patterns

- Parenchymal lung disease
  - thoracic cage restriction
  - Symmetric decrease in TLC, VC, FRC, RV
- Neuromuscular weakness
  - IC mainly decreased
  - TLC and VC decreased
  - FRC and RV spared

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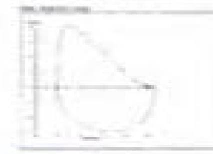


Adult Pulmonary Diagnostic Unit

52427-E

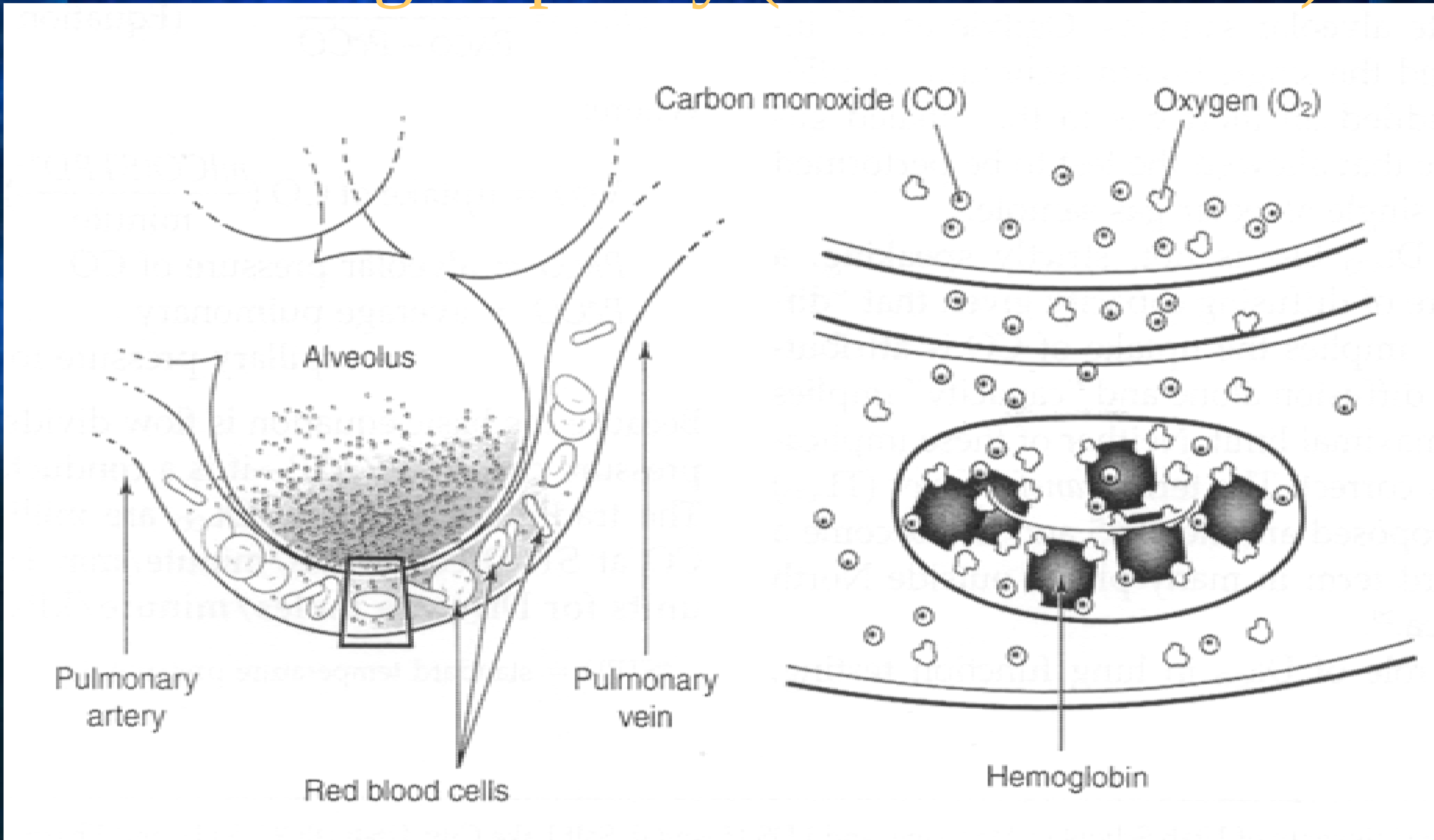
Patient:
Age: **Gender:** Female
Height: 65 in (164 cm) **Weight:**
Body Mass Index:

ID:
Location:
Physician:
Technician:

Date:
Temp:

Spirometry		Ref	Pre Meas	Pre % Ref	Post Meas	Post % Ref	Post % Chg
FVC	Liters	3.51	2.00	57			
FEV1	Liters	2.91	1.52	52			
FEV1/FVC	%	82	76				
FEF25-75%	L/sec	3.18	1.21	38			
FEF25%	L/sec	5.76	3.85	67			
FEF50%	L/sec	3.77	2.14	57			
FEF75%	L/sec	1.55	0.39	25			
PEF	L/sec	6.25	4.32	69			
MVV	L/min	104					
PIF	L/sec	4.31	4.31	100			
FIF50%	L/sec	3.95	4.29	109			
FEF/FIF50			0.50				
FET100%	Sec		7.50				
Lung Volumes							
VC	Liters	3.51	1.87	53			
TLC	Liters	5.14	2.67	52			
RV	Liters	1.69	0.80	47			
RV/TLC	%	33	30				
FRC PL	Liters	2.86					
FRC N2	Liters	2.86	1.23	43			
FRC He	Liters	2.86					
Vtg	Liters						
Diffusion							
DLCO	mL/mmHg/min	27.3	13.8	51			
DL Adj	mL/mmHg/min	27.3	13.8	51			
VA	Liters		2.58				
DLCO/VA	mL/mHg/min/L	5.48	5.37	98			

Diffusing Capacity (Transfer Factor)



Diffusing Capacity for CO (DL_{CO})

- *DL_{CO} = CO rate of uptake (ml/min)/ΔPCO (mmHg)*
- O_2 and CO combine with Hgb
  - reflects properties of alveolar-capillary membrane
  - limited by resistance across this interface
- Soluble gases limited by pulmonary blood flow
- Two major resistances
  - membrane properties (*D*m),
  - “reactive” conductance
    - molecular conformation/rate of reaction properties of Hgb binding x pulmonary capillary blood volume (*V*c)

Diffusing Capacity for CO (DL_{CO})

$$DL_{CO} = \frac{(kCO)(V_A)}{P_b - P_{H_2O}}$$

- kCO = rate constant for CO uptake (aka "permeability factor" or **Krogh coefficient)**
- V_A = alveolar volume
- P_b – P_{H20} = effective gas pressure (barometric pressure - partial pressure of water)
- **Units =** conductance (ml CO/min/mmHg)

Diffusing Capacity for CO (DL_{CO})

- Assumes 100% of alveolar volume was filled with CO
- Influenced by altitude (high altitude decreases PIO_2 and therefore increases DLCO)
- **Note that properties of CO uptake are different than those of oxygen**
  - **CO = diffusion limited**
  - **O_2 = perfusion limited**

Determinants of DL_{CO}

- Gas gradient
- Solubility
- Hemoglobin
- Rate of gas uptake by Hgb
  - Capillary blood volume
- Alveolar-capillary membrane properties
  - Thickness
  - Surface area

DL_{CO} is measured using the single breath Diffusing Capacity for CO manuever

- Inspirate 0.25% CO, 10% inert gas, 21%O_2, balance N_2
- Expire to RV; inhale rapidly to TLC; hold for remainder of 10 seconds of breath hold time
- Expire; discard anatomic dead space gas; sample 500-1000 ml alveolar gas

Limitation of the single-breath Diffusing Capacity manuever

- SB may UNDERESTIMATE true diffusing capacity in emphysema if it underestimates gas dilution V_A since DLCO **=(kcOxVA)/(Pb-PH20)**

Causes of Decreased "Measured" Diffusing Capacity

- Parenchymal Lung problem
  - Loss of alveoli
    - Emphysema
    - Resection
  - Abnormal alveoli (rest of the course…)
- Pulmonary vascular problem
  - Pulmonary vascular disease
  - Pulmonary embolism
- Anemia
- Abnormal hemoglobin

Causes of Increased “Measured” Diffusing Capacity

- Obesity
- Alveolar hemorrhage
- Asthma (?)
- Altitude (?)
- Supine position (vs sitting)
- Left to right shunt

“Diffusion Capacity” vs Diffusion

- Decreased diffusing capacity can result from numerous abnormalities unrelated to diffusion block itself
- Diffusion abnormality as a cause of hypoxemia
  - Diffusion block or other inability to transfer gas completely (eg, low PIO2+ increased circulatory time) so that insufficient transfer of alveolar PO_2 occur
- Decreased diffusing capacity without diffusion block
  - low alveolar volume,
  - low Hgb

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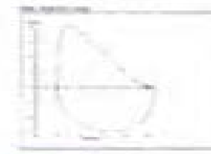

Adult Pulmonary Diagnostic Unit

52427-E

Patient:
Age: **Gender:** Female
Height: 65 in (164 cm) **Weight:**
Body Mass Index:

ID:
Location:
Physician:
Technician:

Date:
Temp:

Spirometry		Ref	Pre Meas	Pre % Ref	Post Meas	Post % Ref	Post % Chg
FVC	Liters	3.51	2.00	57			
FEV1	Liters	2.91	1.52	52			
FEV1/FVC	%	82	76				
FEF25-75%	L/sec	3.18	1.21	38			
FEF25%	L/sec	5.76	3.85	67			
FEF50%	L/sec	3.77	2.14	57			
FEF75%	L/sec	1.55	0.39	25			
PEF	L/sec	6.25	4.32	69			
MVV	L/min	104					
PIF	L/sec	4.31	4.31	100			
FIF50%	L/sec	3.95	4.29	109			
FEF/FIF50			0.50				
FET100%	Sec		7.50				
Lung Volumes							
VC	Liters	3.51	1.87	53			
TLC	Liters	5.14	2.67	52			
RV	Liters	1.69	0.80	47			
RV/TLC	%	33	30				
FRC PL	Liters	2.86					
FRC N2	Liters	2.86	1.23	43			
FRC He	Liters	2.86					
Vtg	Liters						
Diffusion							
DLCO	mL/mmHg/min	27.3	13.8	51			
DL Adj	mL/mmHg/min	27.3	13.8	51			
VA	Liters		2.58				
DLCO/VA	mL/mHg/min/L	5.48	5.37	98			

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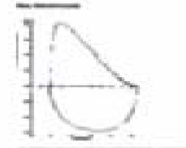

Adult Pulmonary Diagnostic Unit

Patient:

Age: **Gender: Male**

Height: 67 in (169 cm) **Weight:**

Body Mass Index:

ID:

Location:

Physician:

Technician:

Date:

Temp: **PBar:**

Spirometry		Ref	Pre Meas	Pre % Ref	Post Meas	Post % Ref	Post % Chg
FVC	Liters	4.06	2.73	67	2.92	72	7
FEV1	Liters	3.17	1.22	38	1.21	38	-1
FEV1/FVC	%	78	45		41		
FEF25-75%	L/sec	3.03	0.32	10	0.27	9	-14
FEF25%	L/sec	7.41	1.27	17	1.06	14	-16
FEF50%	L/sec	3.57	0.44	12	0.38	11	-13
FEF75%	L/sec	1.22	0.11	9	0.09	7	-21
PEF	L/sec	7.65	4.52	59	4.11	54	-9
MVV	L/min	121			52	43	
PIF	L/sec	3.54	3.64	103	4.35	123	19
FIF50%	L/sec	4.54	3.34	74	3.93	87	18
FET100%	Sec		15.58		19.81		27
Lung Volumes							
VC	Liters	4.06			3.10	76	
TLC	Liters	6.32			6.22	98	
RV	Liters	2.20			3.12	142	
RV/TLC	%	35			50		
FRC PL	Liters	3.29			3.72	113	
FRC N2	Liters	3.29					
FRC He	Liters	3.29					
Vtg	Liters				3.98		
Diffusion							
DLCO	mL/mmHg/min	29.3			11.5	39	
DL Adj	mL/mmHg/min	29.3			11.5	39	
VA	Liters				3.75		
DLCO/VA	mL/mHg/min/L	4.80			3.06	64	

DLCO Pearl

- Isolated DLCO decrease with <u>normal</u> spirometry and volumes
  - Pulmonary vascular disorder
  - Interstitial disorder not yet, or no longer, affecting parenchymal volume
  - Abnormality of Hgb
    - anemia
    - carboxyHgb
    - methHgb

Pre-operative Pulmonary Assessment: PFTs

- Complications: highest for thoracic and upper abdominal (ie, near the diaphragm)
- All having lung resection, orthopoedic and lower abdominal with lung disease, or smoking
- Age>60 years

Postoperative Pulmonary Risks

- Spirometry: FEV_1 or FVC <70%, FEV_1/FVC<65%
- P_aCO_2>45 mmHg, DLCO<40% in COPD
- None contraindicate
- Lung resection: FEV_1 best for pulmonary reserve and post op complications; post op FEV_1 <30% predicted=increased long term mortality and immediate post op problems

PFT Summary

- Obstructive ventilatory defect: decreased FEV_1/FVC
- Restrictive ventilatory defect: decreased TLC
- Low DLCO: abnormal uptake of gas by Hgb across alveolar capillary membrane: Diffusion determinants= Gas gradient, solubility, hemoglobin, membrane thickness, surface area, alveolar volume, rate of circulatory flow
- Disorders with airway dysequilibrium (eg emphysema): single breath gas dilution will underestimate lung volumes (and ? DLCO)

Series ''ATS/ERS TASK FORCE: STANDARDISATION OF LUNG FUNCTION TESTING'' Edited by V. Brusasco, R. Crapo and G. Viegi.

General considerations for lung function testing

Eur Respir J 2005; 26: 153–161