Examinations of Respiratory System

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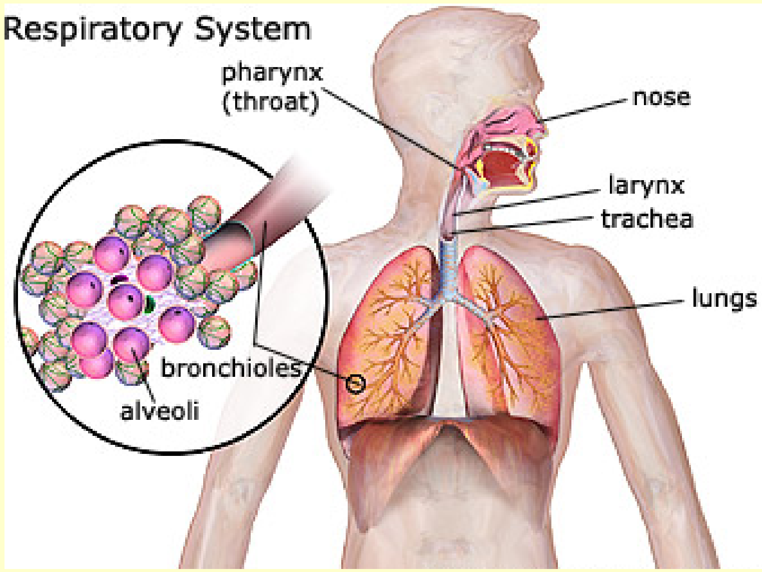
Lung Functions

- To bring oxygen into the body when a person inhales
- To eliminate carbon dioxide from the body when a person exhales
- To help maintain body fluids at a stable acid–base balance.



Evaluation of lung functions

1. **Ventilation**
   – exchange of the air between alveoli and outer environment
2. **Diffusion**
   – gas exchange between alveoli and capillaries
3. **Perfusion**
   – pulmonary circulation
4. **Regulatory mechanisms and function of ventilation** (ABG)

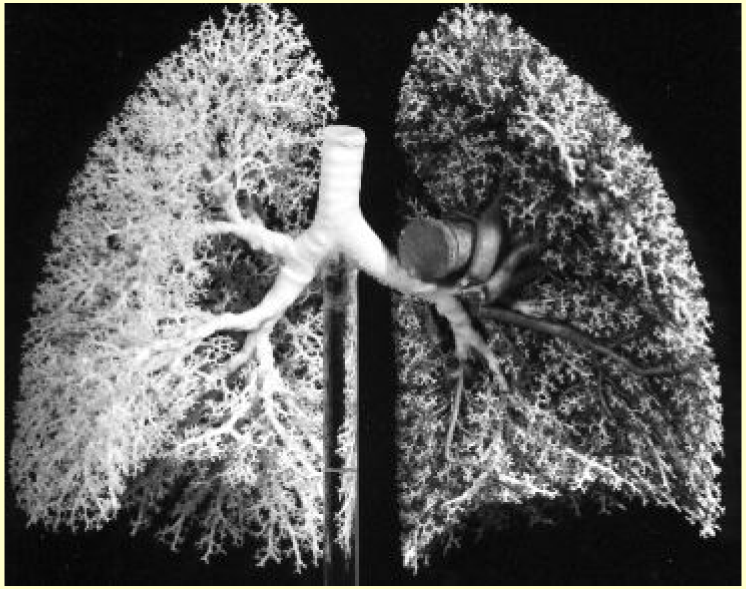
Lung function measurements

- Spirometry (parameters of ventilation)
- Arterial blood gases measurement (ABG)
- Alveolar diffusion
- Ventilation/perfusion scan

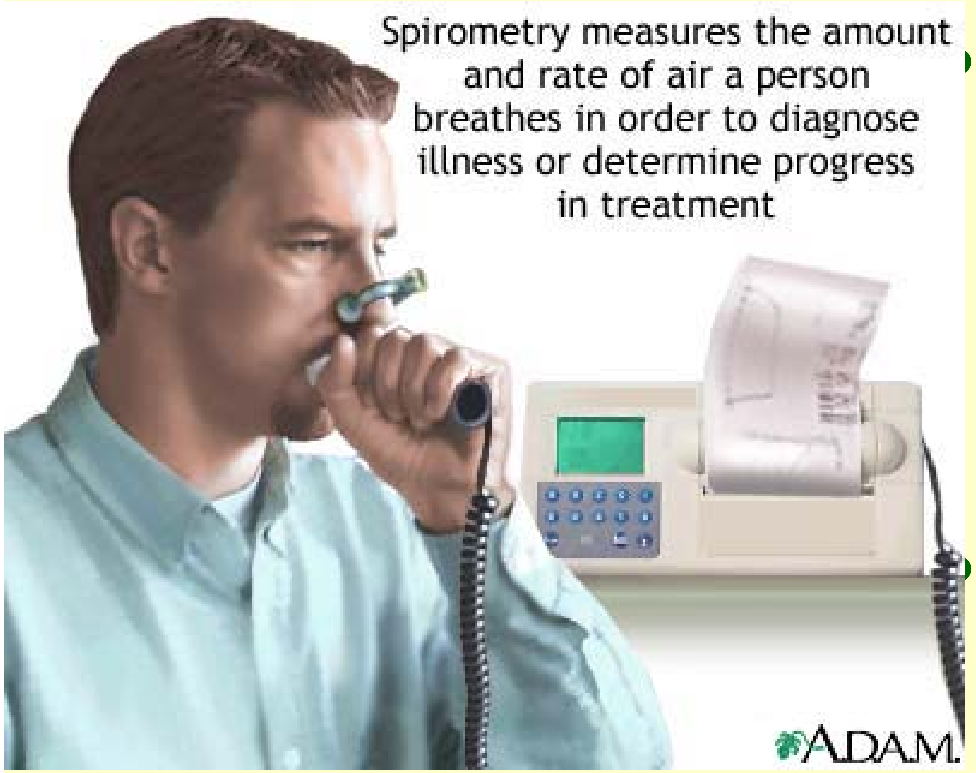
Ventilation

Depends on:

- airway clearness
- lung volume
- lung and chest wall elasticity
- function of breathing center
- function of breathing muscles



Measurement of ventilatory functions
SPIROMETRY



Useful diagnostic tool for patients 5 years of age and older

- Static parameters: lung volumes and capacities
- Dynamic parameters and tests

Test types

- Rest tests
- Stress tests
  - Exercise
    - Spiroergometry
  - Farmacodynamic tests
    - Bronchodilatation
    - Bronchoconstriction

Interpretation of the test results depend on age, sex, height, weight, ethnicity

Indications

1. To identify type and grade of pulmonary dysfunction
2. Evaluation of symptoms and signs (dyspnea, caught, hypoxia)
3. Early diagnosis of lung diseases (in high risk patients)
4. Evaluation of response to the therapy
5. Examination before surgery

Spirometric static ventilation parameters and tests

Lung volumes and capacities

- **VC = Vital capacity:**
  – volume of gas exhaled after the maximal inspiration (measured: Slow VC or Forced VC) (~ 5000 mL)
- **RV = Residual volume:**
  – volume of gas in the lungs after a maximal expirium (~ 1700 mL)

- **TLC = Total Lung Capacity** = VC + RV
  – volume of gas within the lungs after a maximal inspiration (~ 6700 mL)

- **FRC = Functional residual volume:**
  - volume of air left in the lungs at the end of normal exhalation (~ 2900 mL)

- **ERV = Expiratory reserve volume =** FRC – RV
  - (~ 1200 mL)

Spirometric dynamic ventilation parameters and tests

- Ventilatory rate
  - ~ 12 breaths / min
- Respiratory minute volume (Minute ventilation)
  - 6-8 L/min

Forced Vital Capacity (FVC)

- Total volume exhaled during the forced expiration

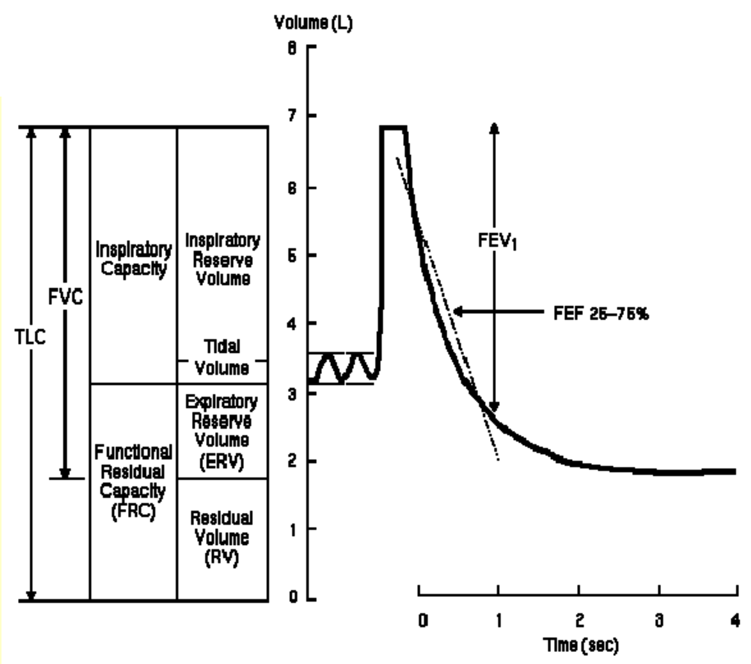
- **F:** [21.7 – (0.101 x **age**)] x **height** (cm) = (mL)

- **M:** [27.63 – (0.112 x **age**)] x **height** (cm) = (mL)

- Values between 80 to 120 % of predicted are considered to be normal

Forced expiratory volume in 1 second FEV1

- Volume of gas exhaled during the first second of forced expiration
- Typically decrease in patients with obstructive pulmonary diseases
- Tiffeneau index:
  - FEV1[%] = (FEV1 / FVC) x 100 %
  - normal value: ~ 80 %



Use of Tiffeneau index (FEV1/FEV) for diagnosis of COPD

- Tiffeneau index < 70% of FVC
- Tiffeneau index is less than 80% of predicted (NICE, Great Britain)
- Tiffeneau index is less than 88% of predicted for males and 89% of predicted for females (European Respiratory Society, ERS)

COPD

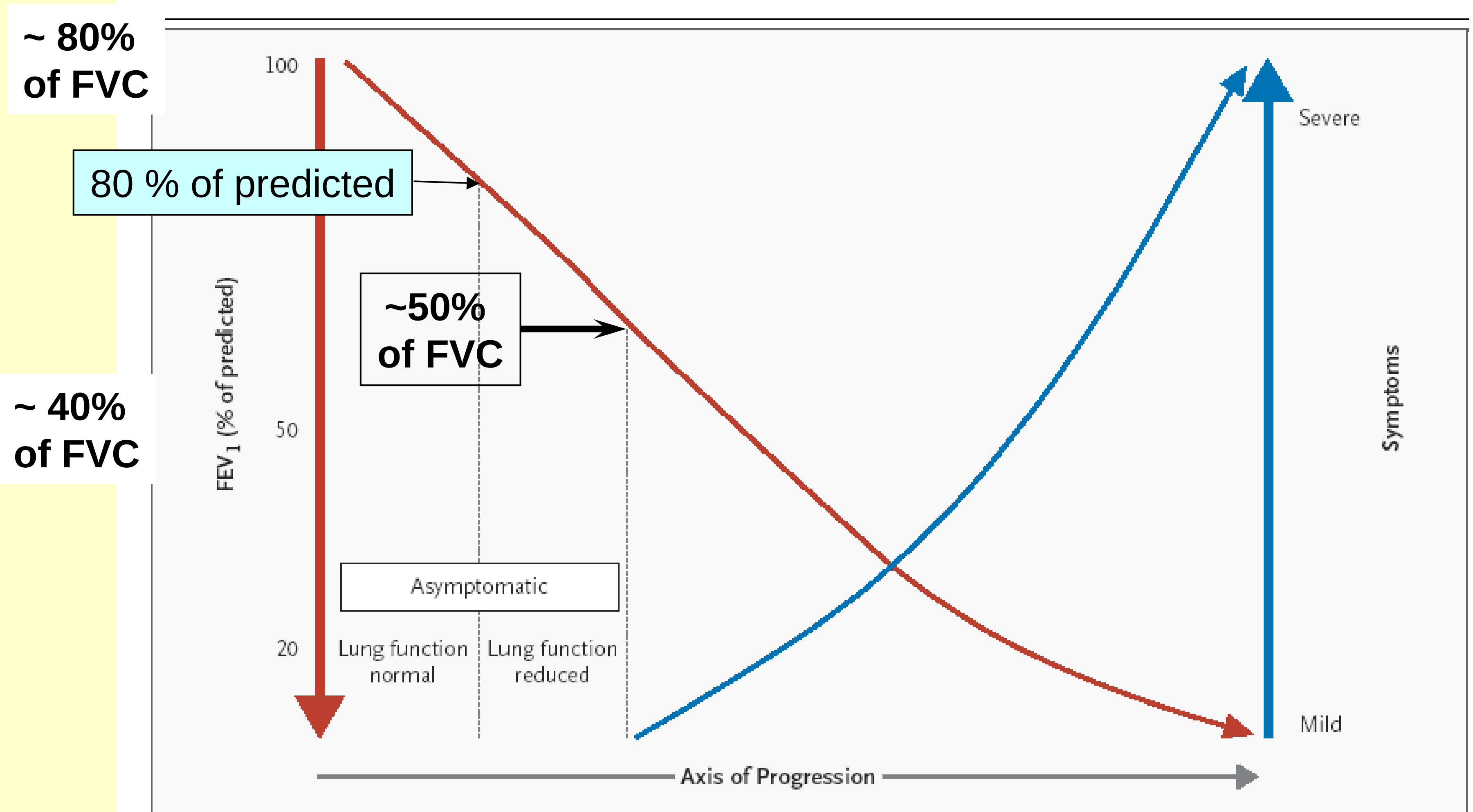
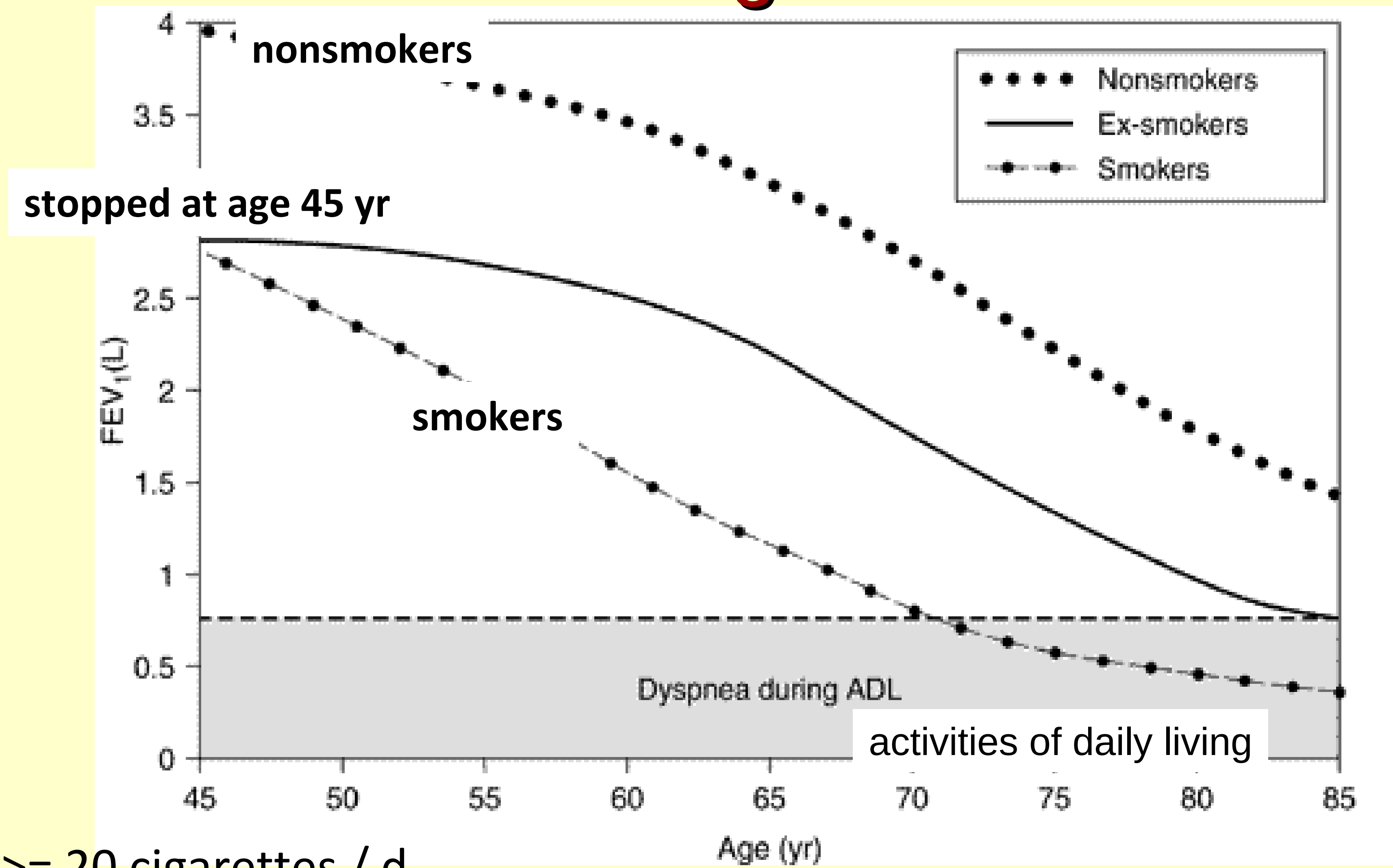


Figure 1. Deterioration in Lung Function in Patients with COPD.
Symptoms generally develop only after a significant decline in forced expiratory volume in one second (FEV_1) has occurred; they progress as lung function deteriorates further.

Decline of FEV1 with age and smoking status



>= 20 cigarettes / d

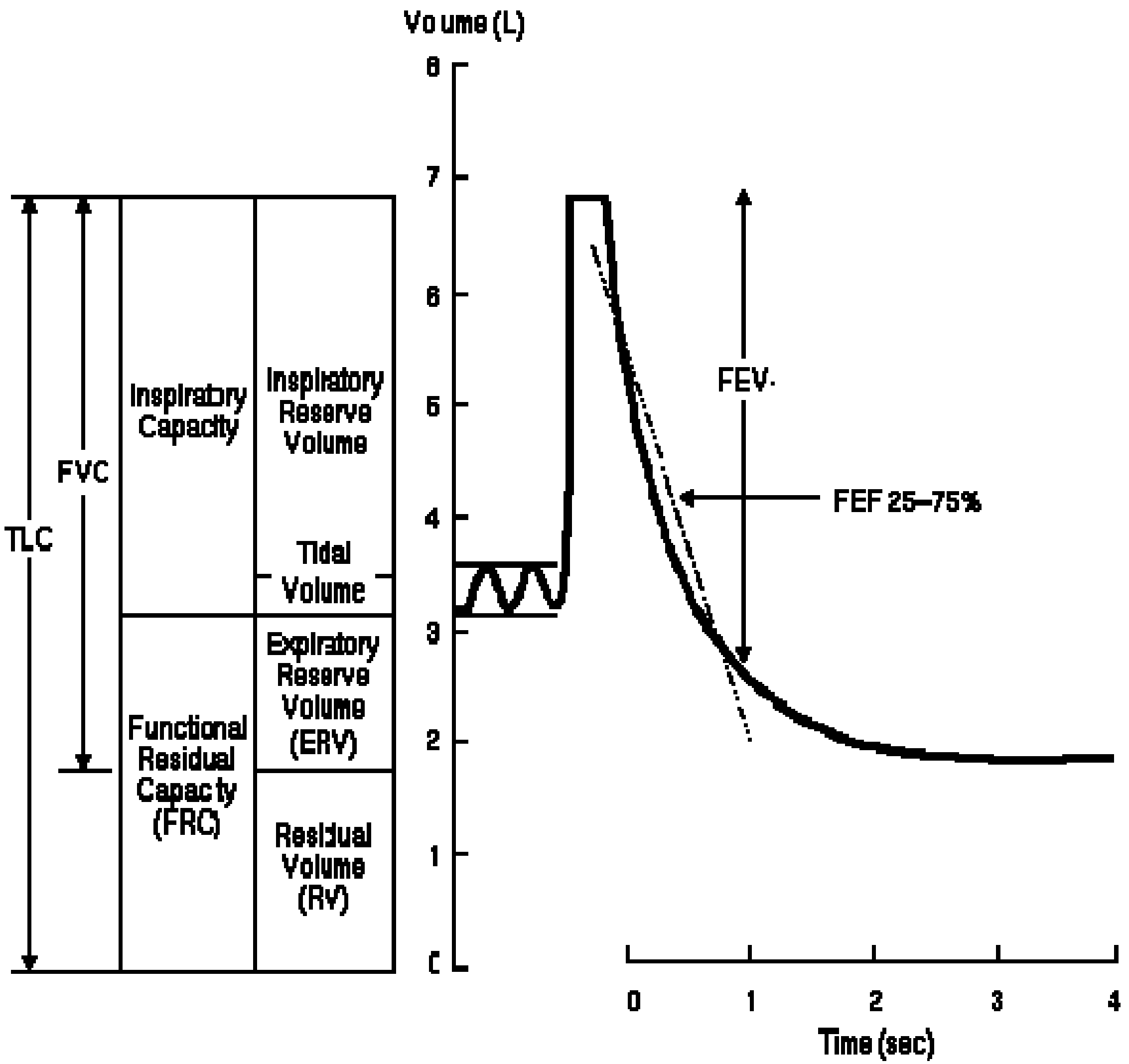
>= 25 yr.

Snider GL: "Chronic obstructive pulmonary disease," in Stein JH, editor: Internal Medicine, ed. 5, St. Louis, 1998, Mosby-Year Book, Inc.;

Forced expiratory flow from 25 to 75 % of the vital capacity (FEF25-75%)

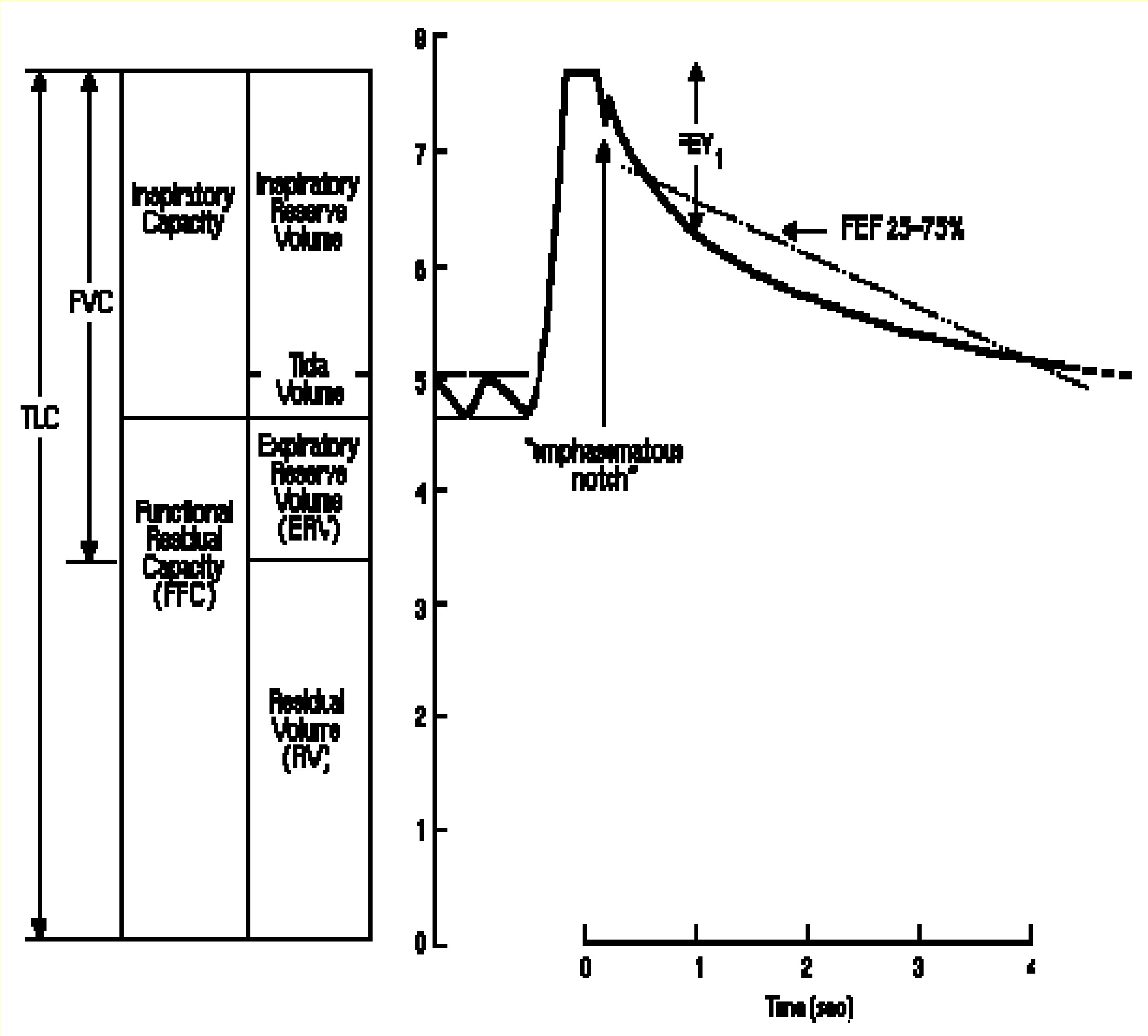
- (Also: MMFR = Maximal Mid-expiratory Flow Rate)
- Often more sensitive measurement of early airflow obstruction then FEV1
  - normal values: 2 – 4 L/sec
- False results may be obtained in patients with abnormally small lungs

Normal spirogram
Volume – time curve



- RV ~ 25% of TLC
- FEV1 > 75 % of FVC
- FRC ~= 40% of TLC

Airway Obstruction



↓ FVC

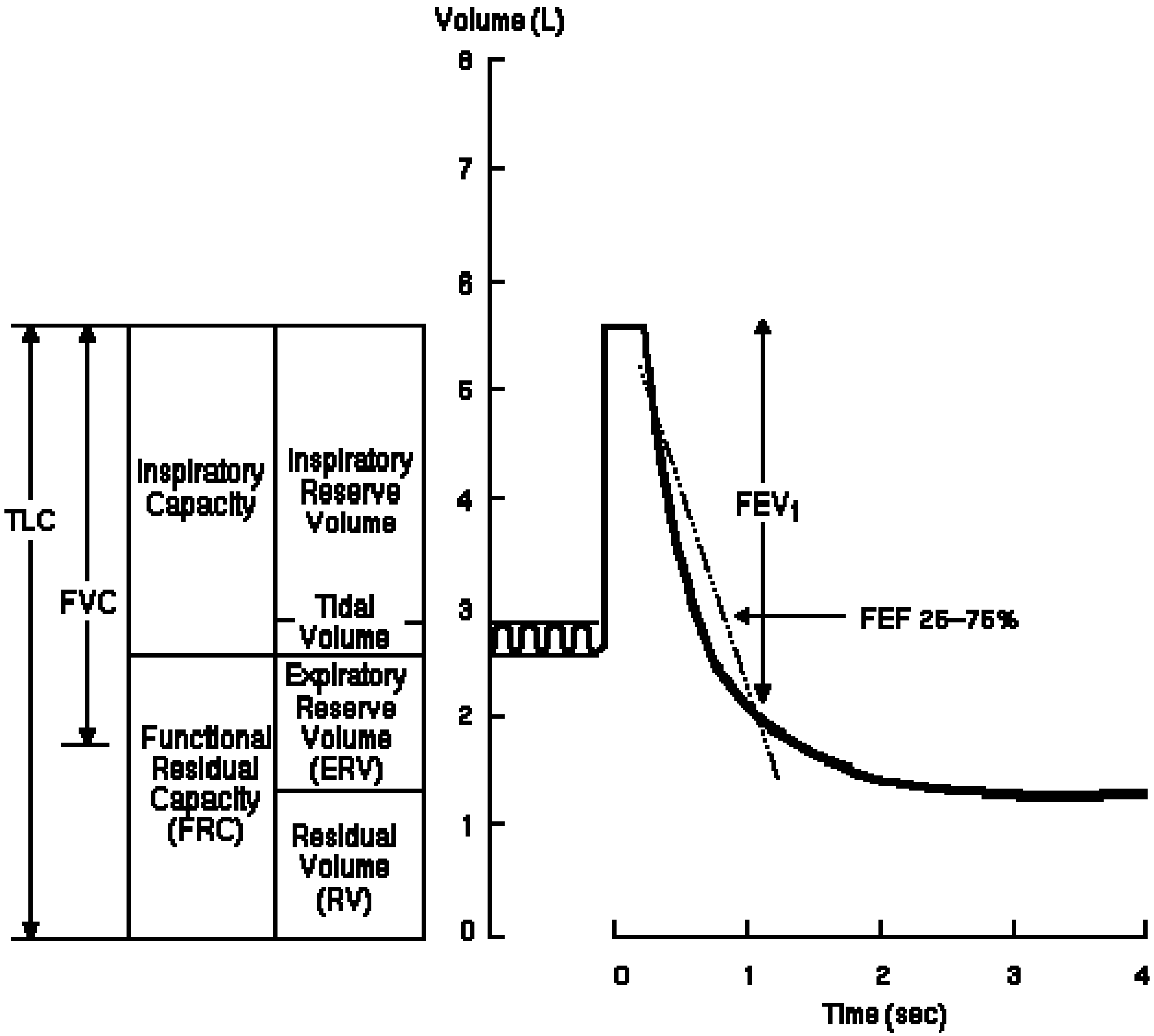
↓ FEV1

FEV1 <= 70% of FVC

↑ TLC

↑ RV

Restrictive Disease



↓TLC

↓ FVC

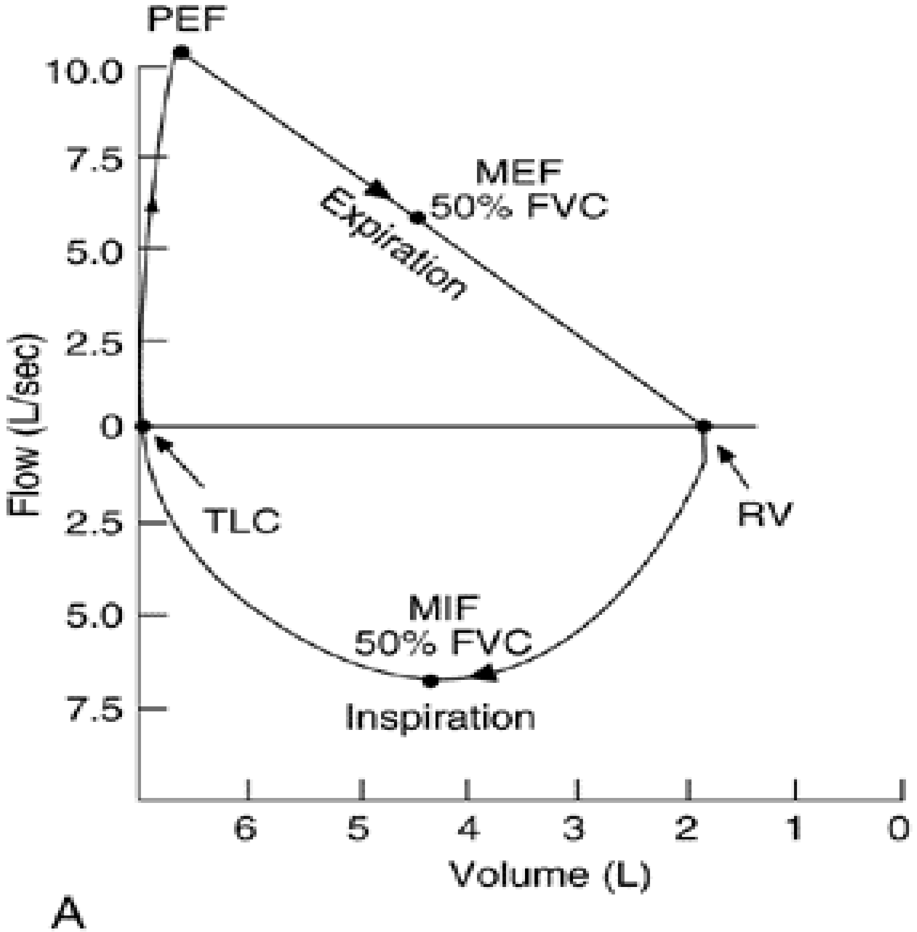
FEV1/FVC normal

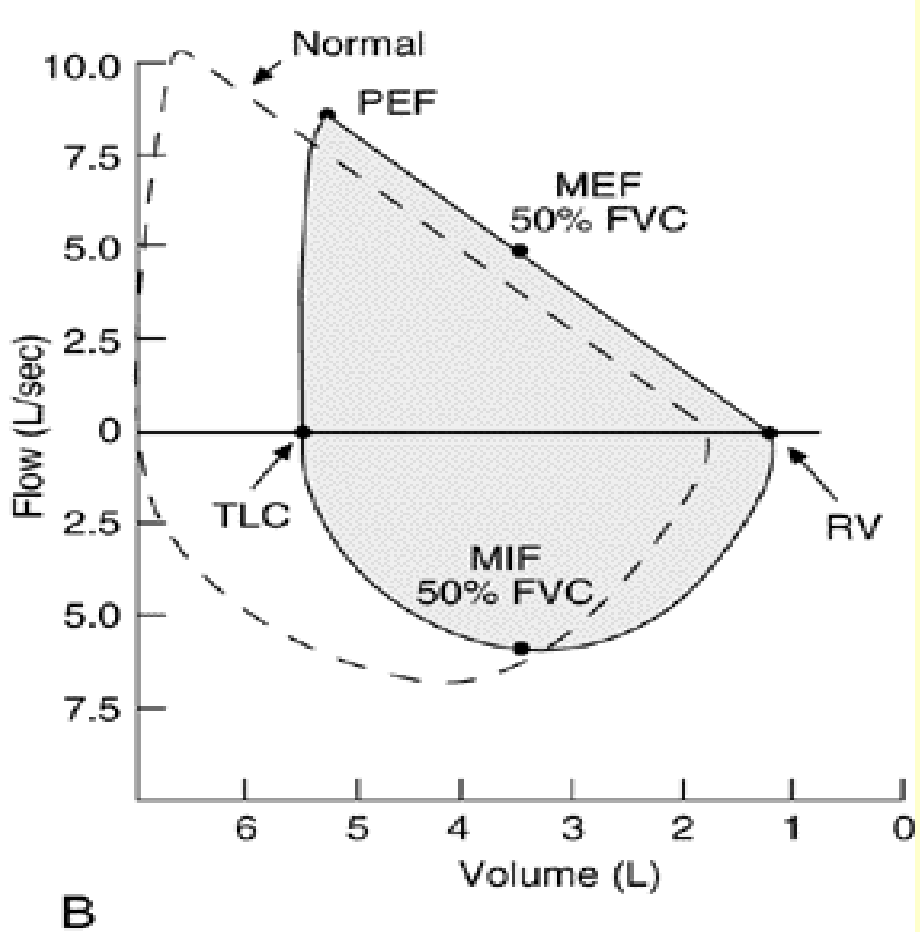
↓RV

Tidal breathing is rapid and shallow

Flow volume curves

Normal | Restrictive disease



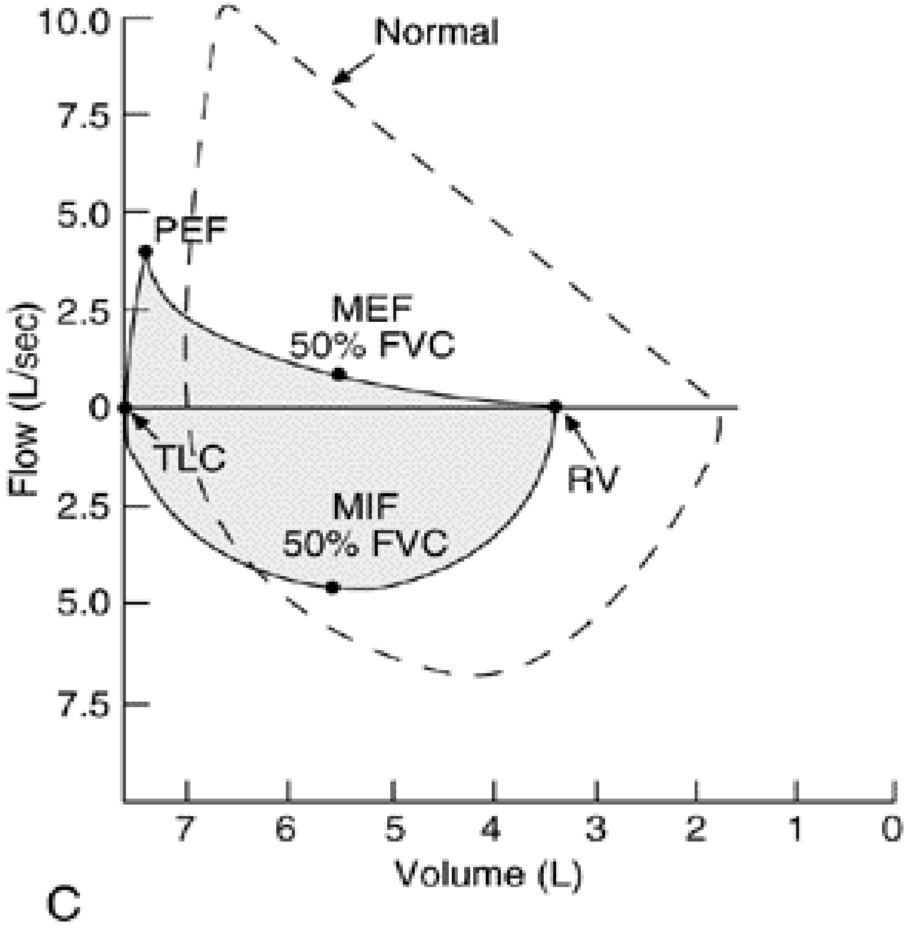


- Inspiratory limb of loop is symmetric and convex
- MIF 50%FVC is > MEF 50%FVC

- Loop is narrowed because of diminished lung volumes
- Flow rates are normal

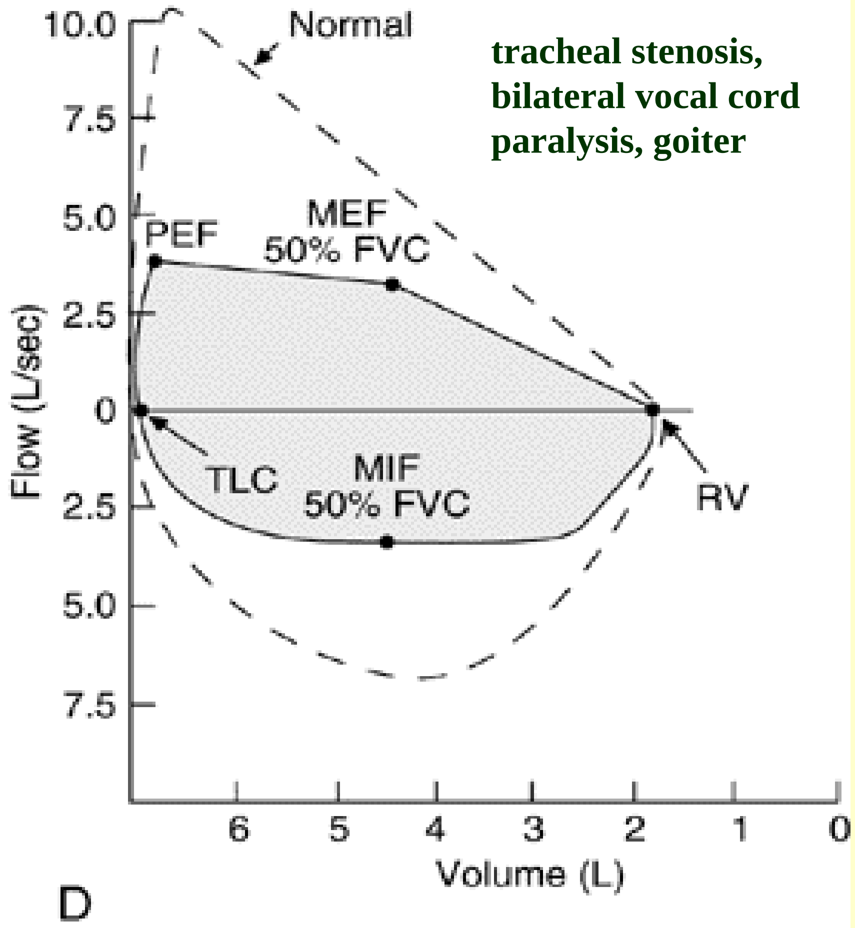
Flow volume curves - obstruction

Small airway obstruction
(Asthma, COPD)



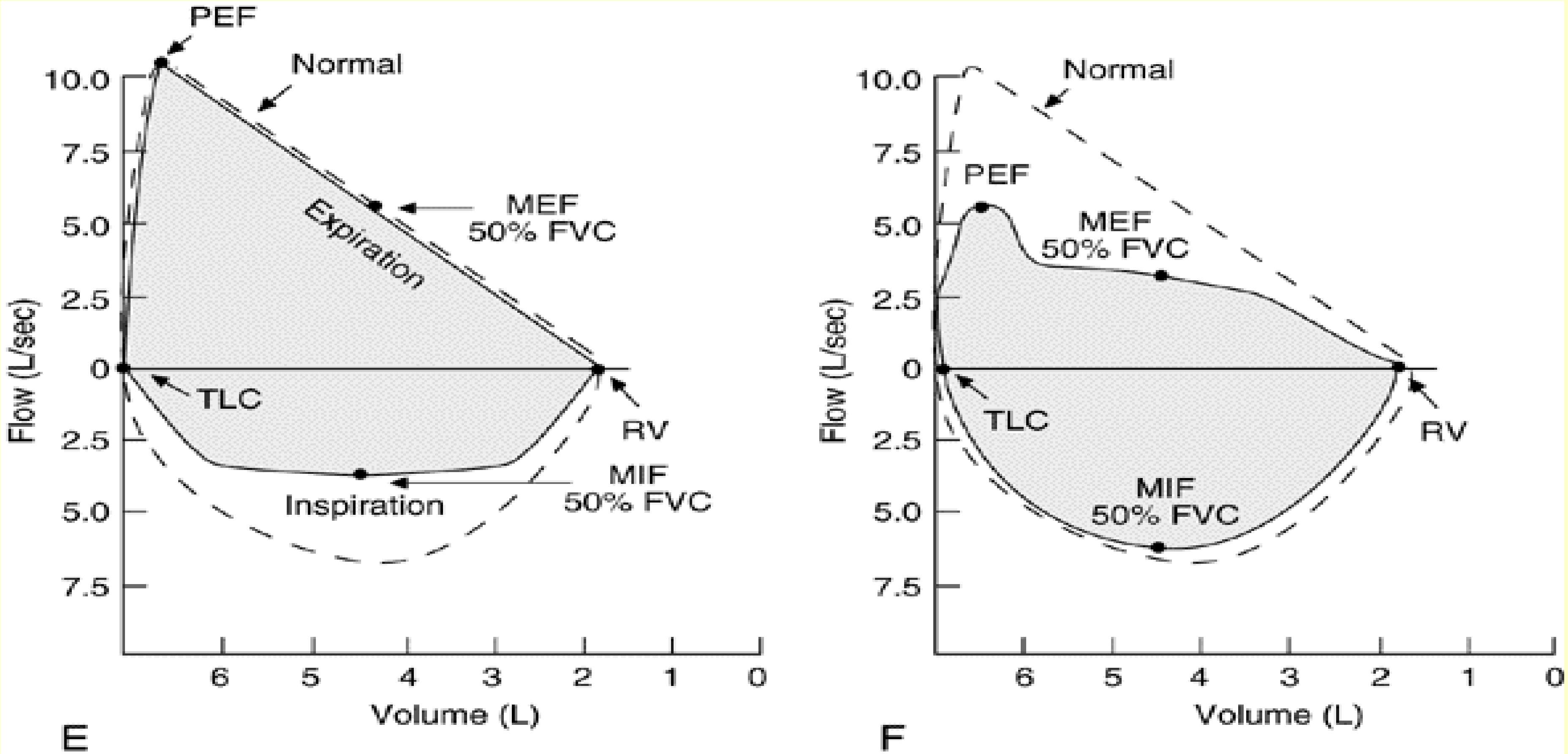
Flow rates are diminished, expiratory prolongation

Fixed obstruction of upper airway



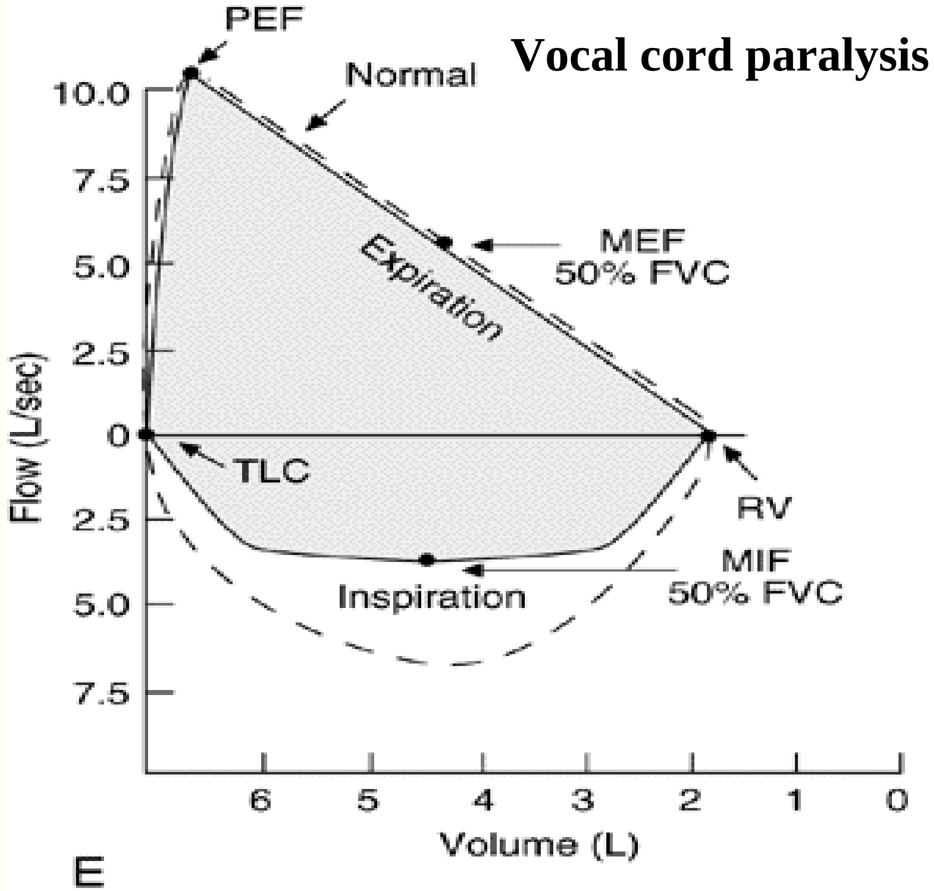
Limits flow equally during inspiration and expiration (MEF = MIF)

Flow volume curves - obstruction



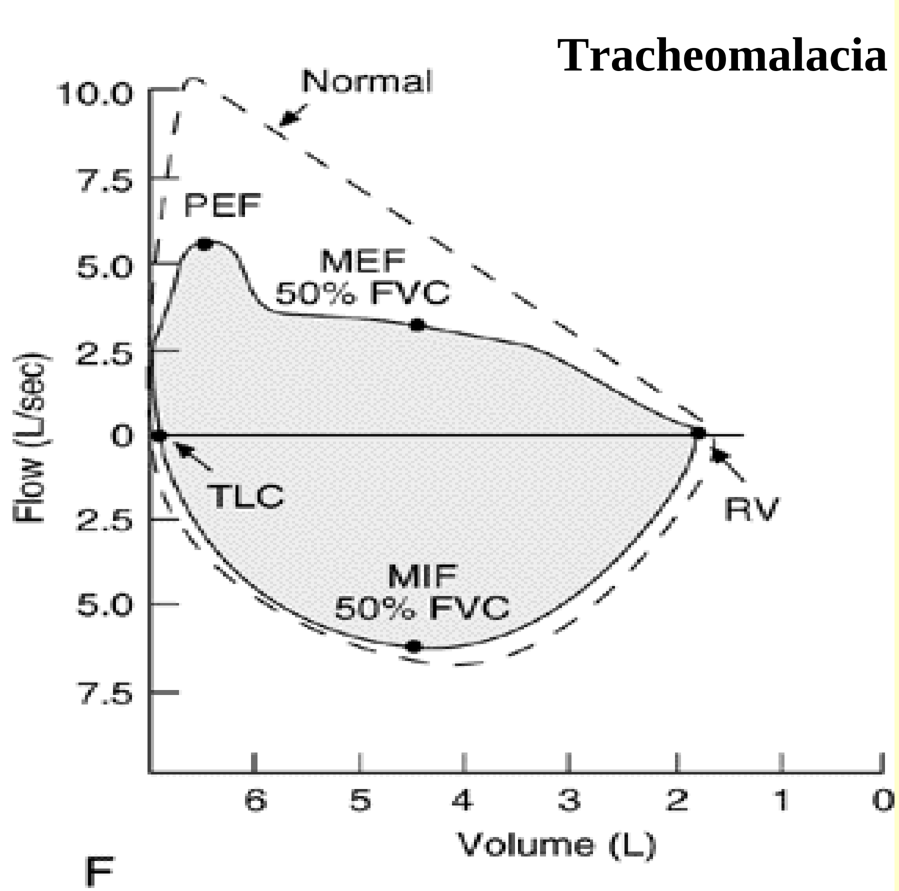
Flow volume curves - obstruction

Variable extrathoracic obstruction



MIF 50%FVC is < MEF 50%FVC

Variable intrathoracic obstruction



Expiration result in the loss of structural support

Peak expiratory flow rate (PEFR)

- (Wright’s) Peak flow meter (late 1950s)
  - hand-held device used to monitor a person's ability to breathe out air.

~ 1980

2009

Maximal minute ventilation

- MMV (Vmax) = Maximal minute ventilation
  - maximal tidal volume (TV) and maximal ventilatory rate for 10 – 30 sec. (Normal > 40 L/min)

- Ventilarory reserve = Respiratory minute volume / MMV
  - normal values: > 1 : 5
  - ~ 1 : 2 dyspnea when patient is resting

HYPOVENTILATION

decrease in air exchange between alveoli and outer environment

- Decreased minute ventilation (or delivery of oxygen because of low PiO_2)

- **Arterial blood gases (ABG)**
  - PaO_2 – decreased (< 80 mmHg)
  - $PaCO_2$ – increased (> 45 mmHg)
- **Alveolar gases**
  - $PACO_2$ – increased
    - dependent on **ventilation**
  - PAO_2 - decreased
    - dependent on **ventilation, diffusion, and perfusion**

HYPOVENTILATION

How to determine whether hypoventilation is complicated by decreased diffusion and/or perfusion

- Alveolar-arterial gradient for oxygen
  - PAO2 - PaO2
- A normal PAO2 - PaO2 ~ 10 mmHg
  - physiologically increases with age
- Predicted PAO2 - PaO2 depends on age:
  - **< (age/4) + 4 [mmHg]** (40 year < 14 mmHg)

HYPOVENTILATION

How to determine whether hypoventilation is complicated by decreased diffusion and/or perfusion

- Abnormally increased PAO2 - PaO2
  - diffusion defects
  - V/Q (ventilation/perfusion ratio) defect
  - right-to-left shunt

- To determine PAO2 - PaO2
  - We need to **calculate** alveolar PO2 (PAO2)

Calculation of alveolar PO2 (PAO2)

- The calculation relies on the following assumptions:
  - Inspired gas contains no carbon dioxide (CO2)
    - PiCO2 = negligible (0.3 mmHg)
  - Other gases (e.g. nitrogen) except oxygen in the inspired air are in equilibrium with their dissolved states in the blood
  - The alveolar and arterial partial pressures of CO2 are equal (1-2 mmHg difference)
  - The alveolar gas is saturated with water
  - Daltons law applies
    - Total pressure of gases in a mixture is equal to the sum of the partial pressures of the constituent gases (for air: O2 + CO2 + others = PB

Calculation of alveolar PO_2 (PAO_2)

- Oxygen in upper airways (PO_2):
  - PB = Barometric pressure (760 mmHg at sea level)
  - subtract water vapor pressure (47 mm Hg) 100% saturation in the airways
  - FiO_2 (0.21) = fraction of oxygen in the air
  - $PO_2 = FiO_2 \times (PB - PH_2O)$
    - Partial pressure of oxygen **in the upper airway** air at sea level (**150 mmHg**)

How to determine the PAO2-PaO2 ?

- Air upper airways (calculated based on PB):
  - **Partial pressure of oxygen in the upper airway air at sea level (150 mmHg)**

- **Arterial blood gassed are measured**
  - PaCO2 **(~40 mmHg)**
  - PaO2 (~90 mmHg)

How to determine the PAO2-PaO2 ?

- **assumption PACO2 = PaCO2**
- Relation between O2 consumption and CO2 production?
  - **respiratory quotient** = 0.8
  - i.e. RQ = CO2 produced / O2 consumed
- **Alveolar PAO2**
  - PAO2 = PO2 upper airways - PaCO2/0.8

- PAO2 - PaO2
  - Expected A-a gradient < (Age/4) + 4
  - can range from 5-20 mmHg

Example

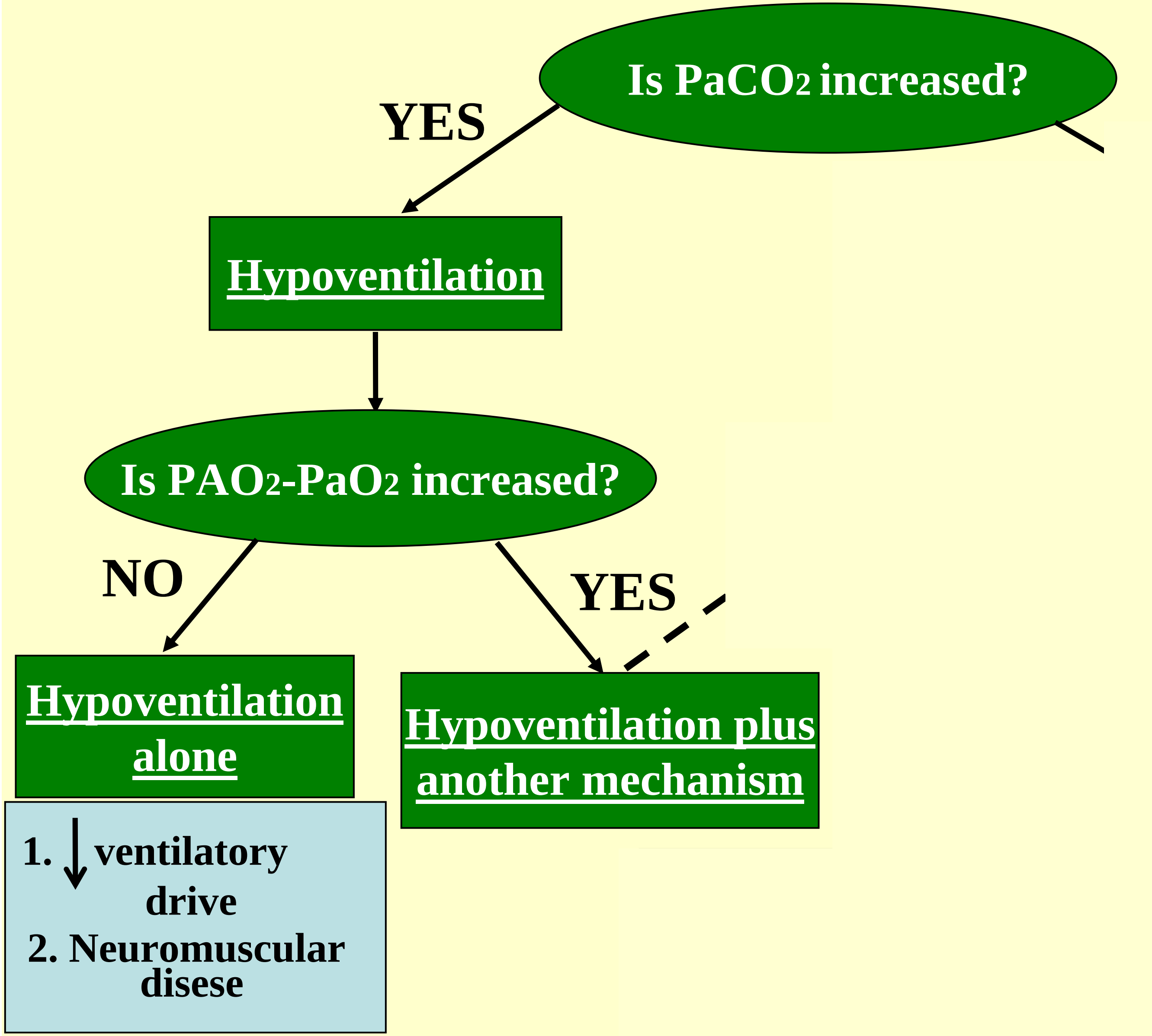
- A 20-year-old woman is brought to the emergency room with an altered level of consciousness. Her boyfriend states he came home from work to find her "asleep" on the sofa, but when he tried to wake her, she just mumbled. The boyfriend wonders if this might be caused from her taking too much pain medicine since she sprained her ankle a few days ago. He does not think she takes any other medications or has any drug allergies.

  On exam, she is breathing 8 times per minute; her ABG is:

  - pH = 7.21
  - P_aCO_2 = 75 mmHg
  - P_aO_2 = 41 mmHg

Diagnostic approach to the patient with hypoxemia

(PaO_2<80 mmHg ~ 10.6kPa)



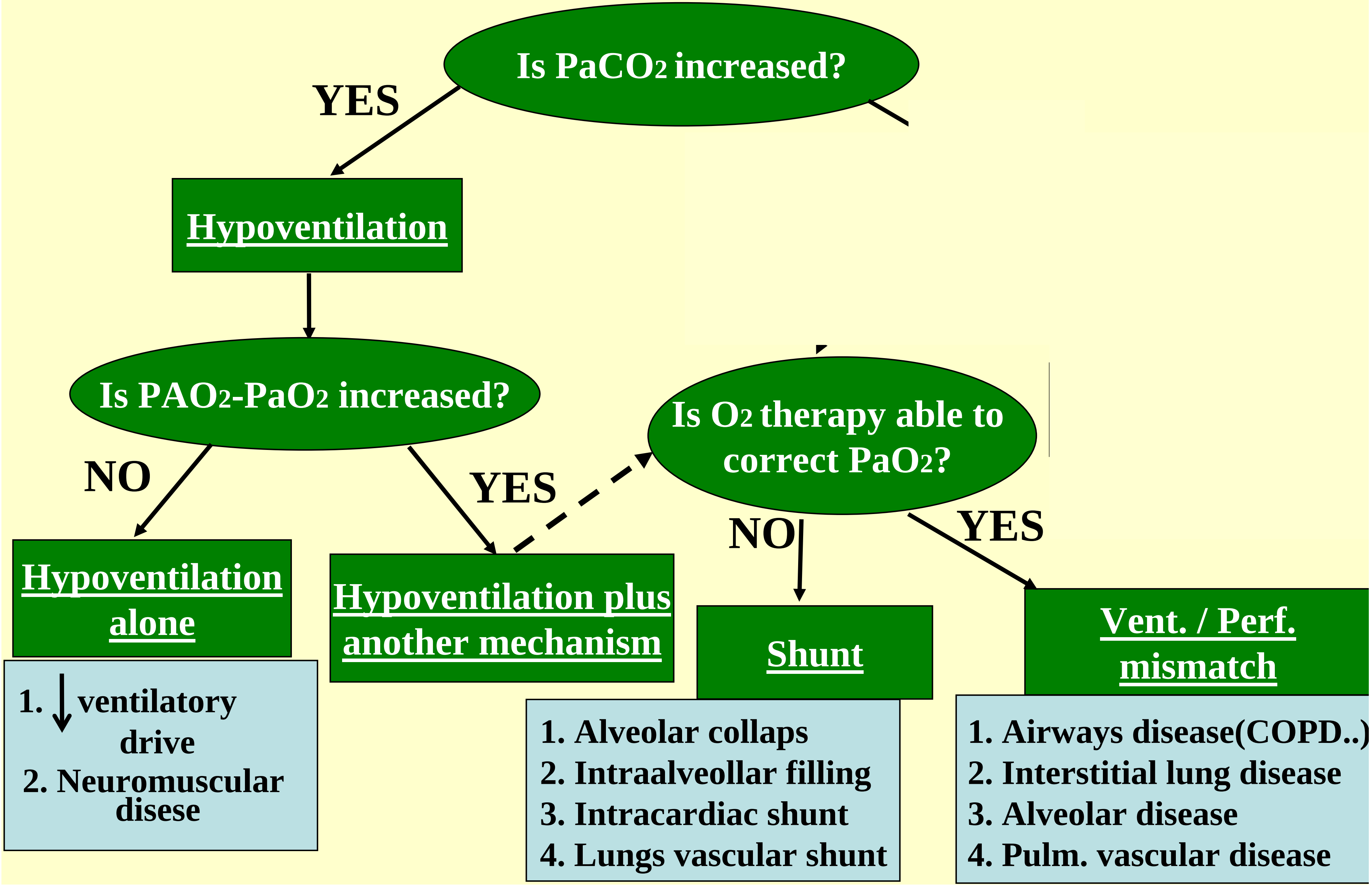
Example

- Could hypoventilation be a cause of her low PaO2?
  - Yes: P_{aCO2} is high

Difusion/Perfusion

Diagnostic approach to the patient with hypoxemia

(PaO_2<80 mmHg ~ 10.6kPa)



Example

- Could hypoventilation be a cause of her low PaO_2?
  - Yes: P_{aCO_2} is high

Calculated P_{AO_2}

- pH = 7.21
- P_{aCO_2} = 75 mmHg
- P_{aO_2} = 41 mmHg

- P_{AO_2}
  - A) 76 mmHg B) 56 mmHg C) 150 mmHg

- $P_{AO_2} = F_{iO_2} \times (P_B - P_{H_2O}) - P_{aCO_2}/0.8$
- P_{AO_2} = 0.21 x (760 - 47) – 75/0.8 = **56 mmHg**

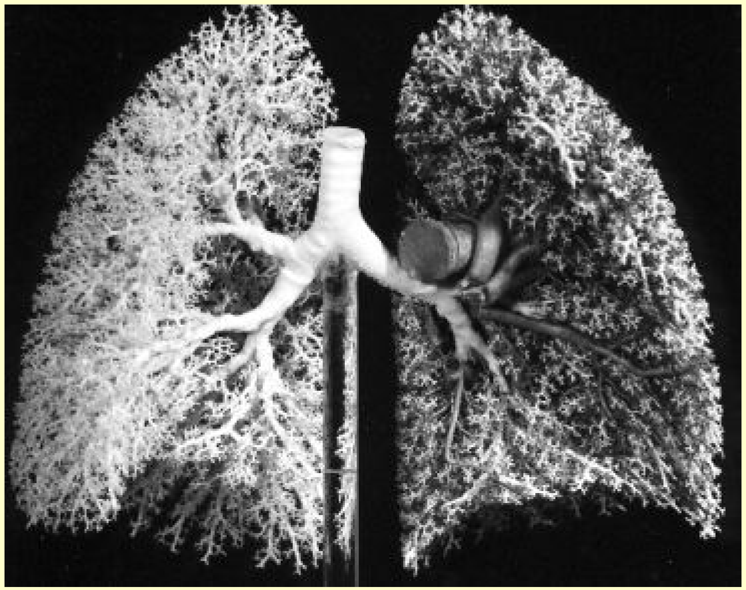
Example

- What is the PAO2- PaO2 gradient of a 20-year-old female is breathing room air, at sea level, and his ABG is:
  - pH = 7.21
  - P_{aCO2} = 75 mmHg
  - P_{aO2} = 41 mmHg
  - P_{AO2} = 56 mmHg
- PAO2- PaO2 = 15 mmHg
- Predicted = $\leq$ 9 mm Hg [(20/4)+4]

Example: Conclusion

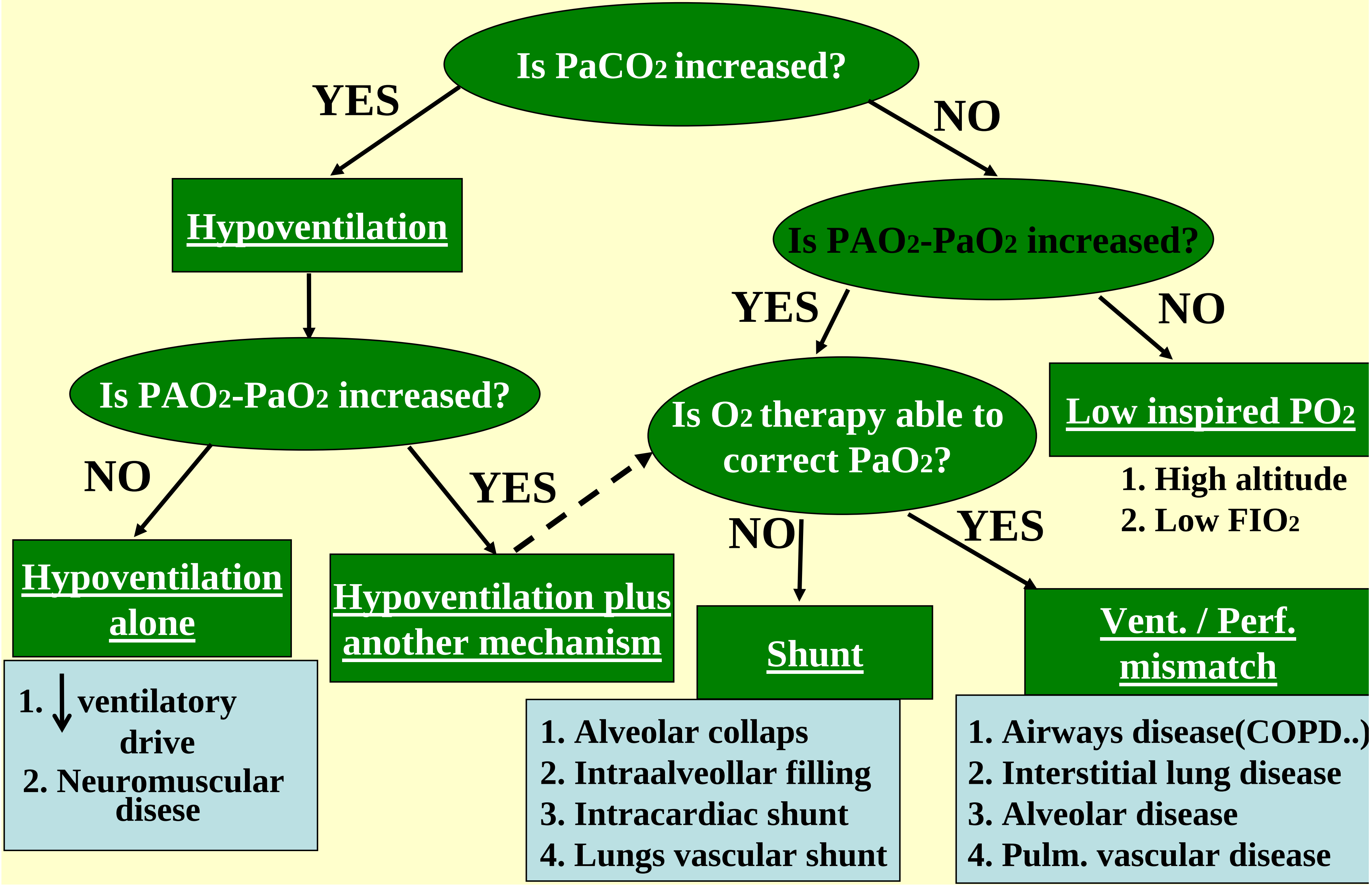
- Patient has been hypoventilating based on her elevated $PaCO_2$
- Hypoxemia is not caused solely by hypoventilation. Based on Elevated A-a O_2 gradient.
  - Possible aspiration pneumonia (chest x-ray)

Diffusion and perfusion

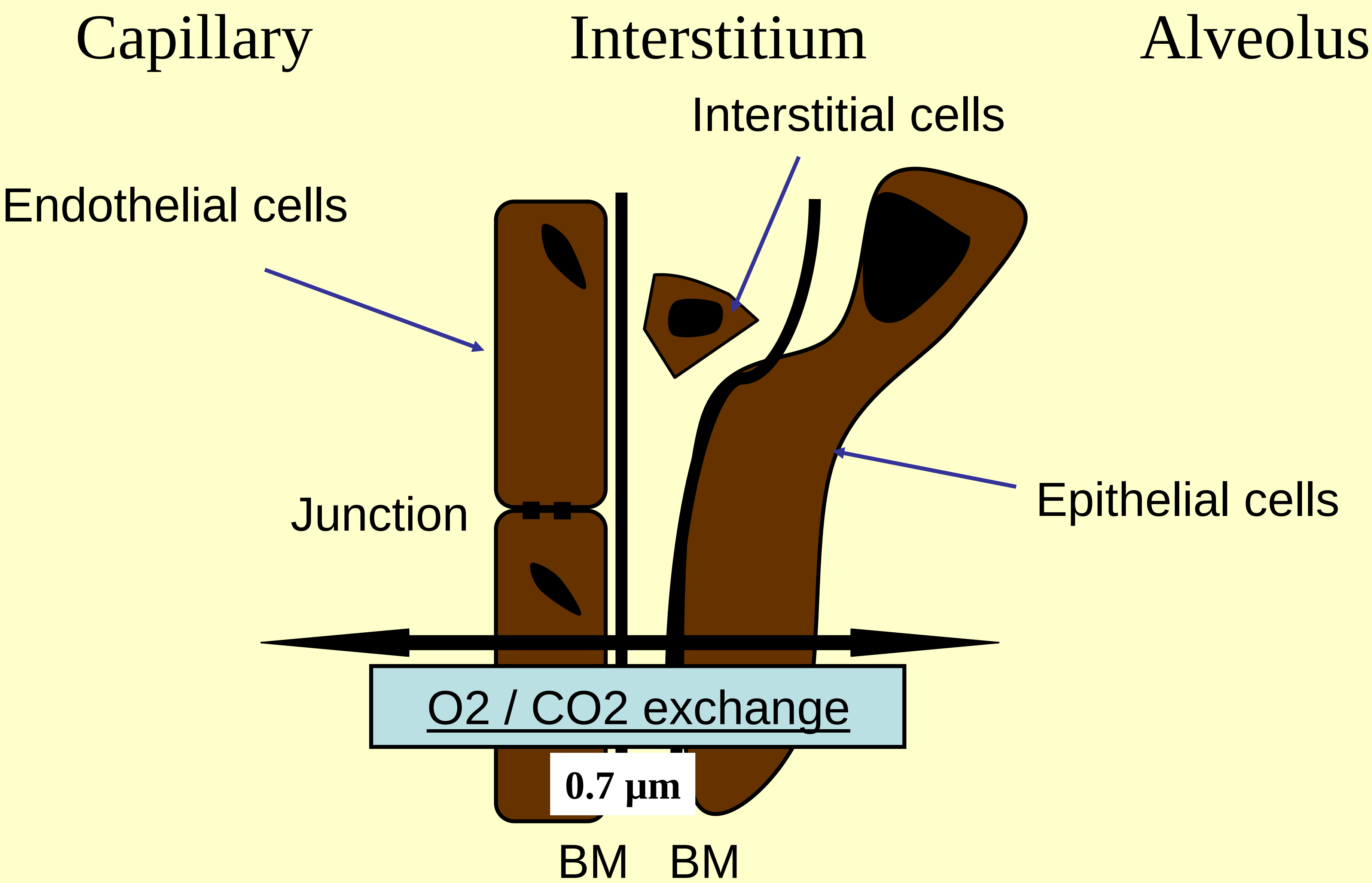


Diagnostic approach to the patient with hypoxemia

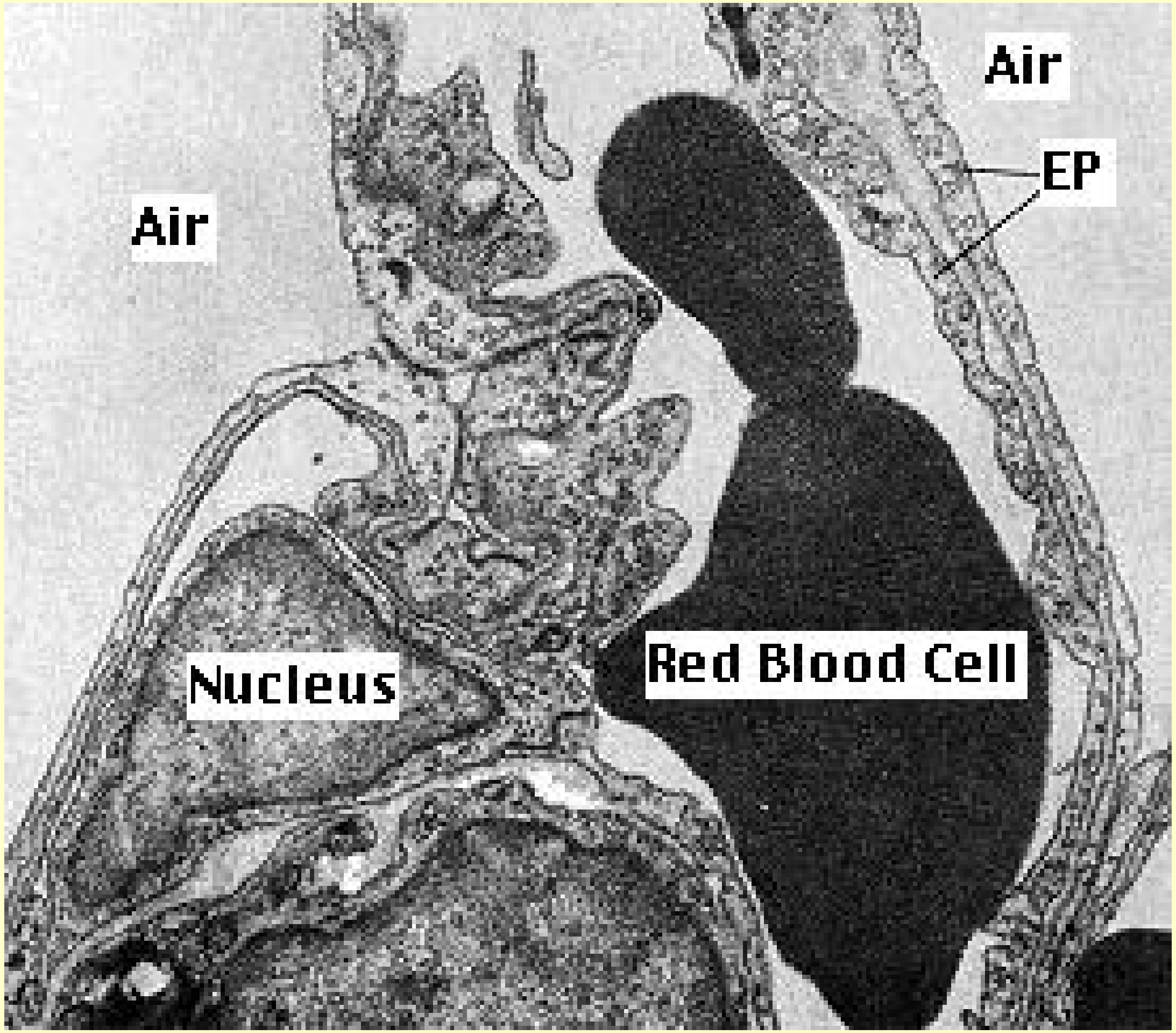
(PaO_2<80 mmHg ~ 10.6kPa)



Alveolo-capillary membrane



Alveolo-capillary membrane electron micrograph



Causes of decreased difusion

- Abnormal ventilation / perfusion mismatch
- Increased thickness of alveolo-capillary membrane
- Destruction of alveolar membrane
- Decrease level of hemoglobin (Anemia)
- Hb with bound CO (Carboxyhemoglobin) (smokers, Co intoxication)

Evaluation of alveolo-capillary diffusion and lung perfusion

- Blood gases (Astrup)
  - Partial pressure of gases in alveoli and arterial - alveoli ratio of oxygen partial pressure
    - –paO_2, $paCO_2$, pAO_2, $P(\mathbf{A}\text{-}a)O_2$
- Blood pressure in pulmonary artery
  - mean PAP < 20 mmHg [2.67 kPa]; PAP =15-30/5-13 mmHg
  - – Flow directed pulmonary arterial (Schwan-Ganz) catheter
  - – Diseases which cause hypoxemia are potentially capable of increasing pulmonary vascular resistance (COPD, interstitial lung disease, chest wall disease, recurrent pulmonary emboli...)

Evaluation of alveolo-capillary diffusion

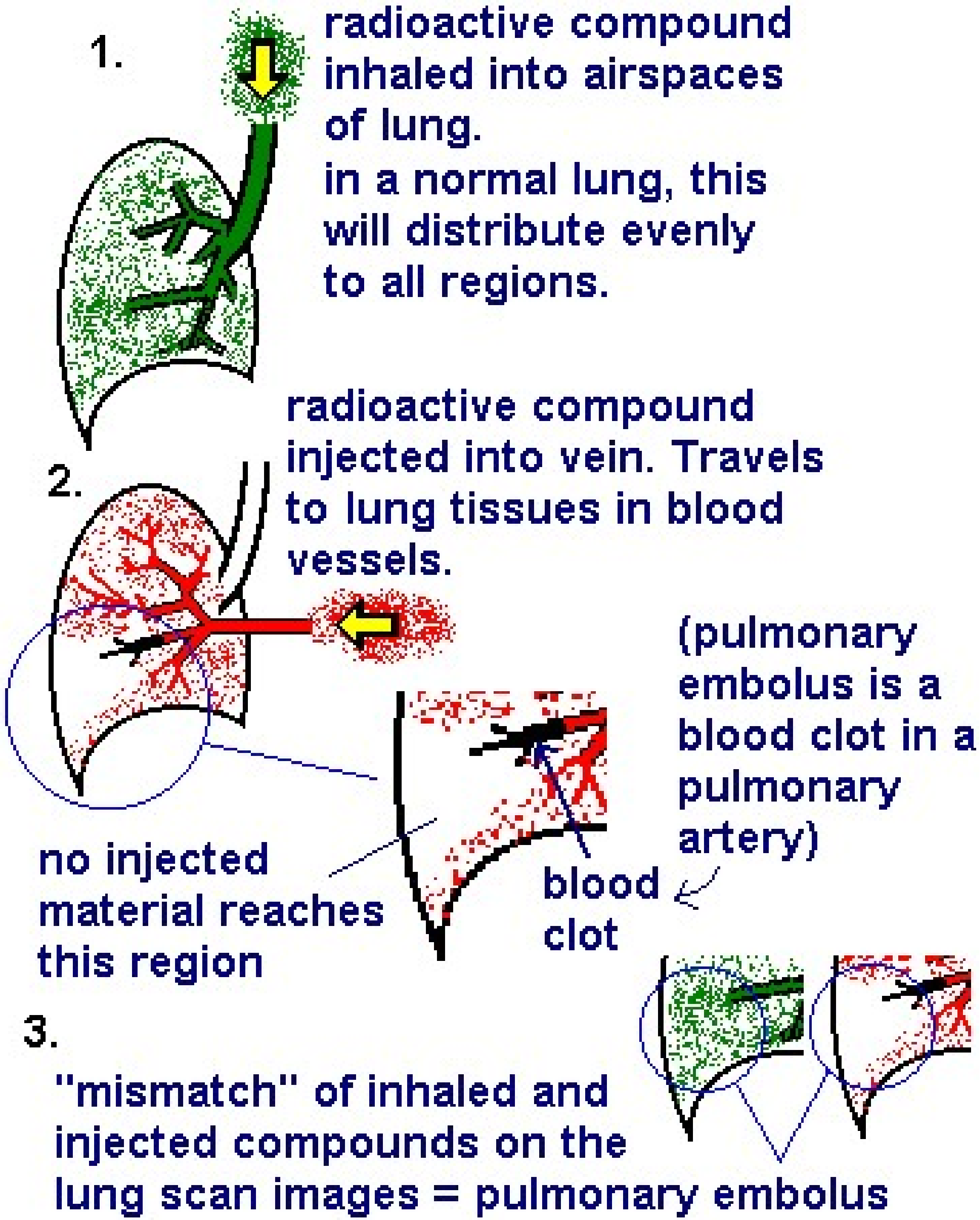
- Diffusion capacity of the lungs
  - is measured for CO (DLCO)
  - for O_2 = DLO_2 = 1.23 x DLCO

  - should be between 75% and 125% of the average
  - Procedure:
    - single-breath breath-holding technique.
      - subject inhales a known volume of test gas (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.

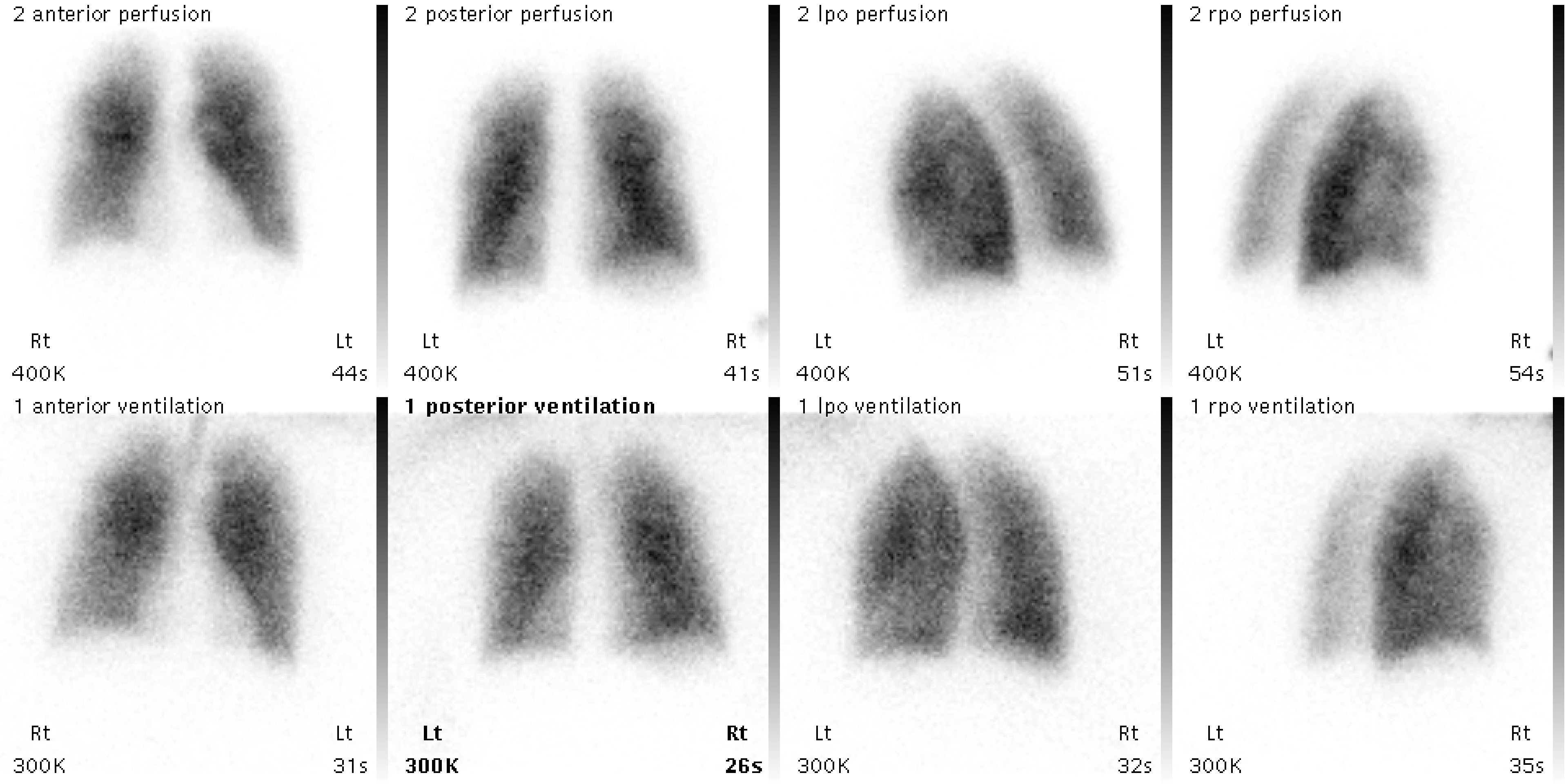
Ventilation - perfusion scan

- Diagnosis of pulmonary embolism and parenchymal lung disease
  - should be performed in clinically stable patients with the suspicion of pulmonary embolism
      - Ventilation scan - 133Xe gas
      - Perfusion scan – microspheres of albumin (50-100 μm labeled with gamma emitting isotope 99mTc
      - - “Mismatch” in ventilation and perfusion is characteristic for PTE

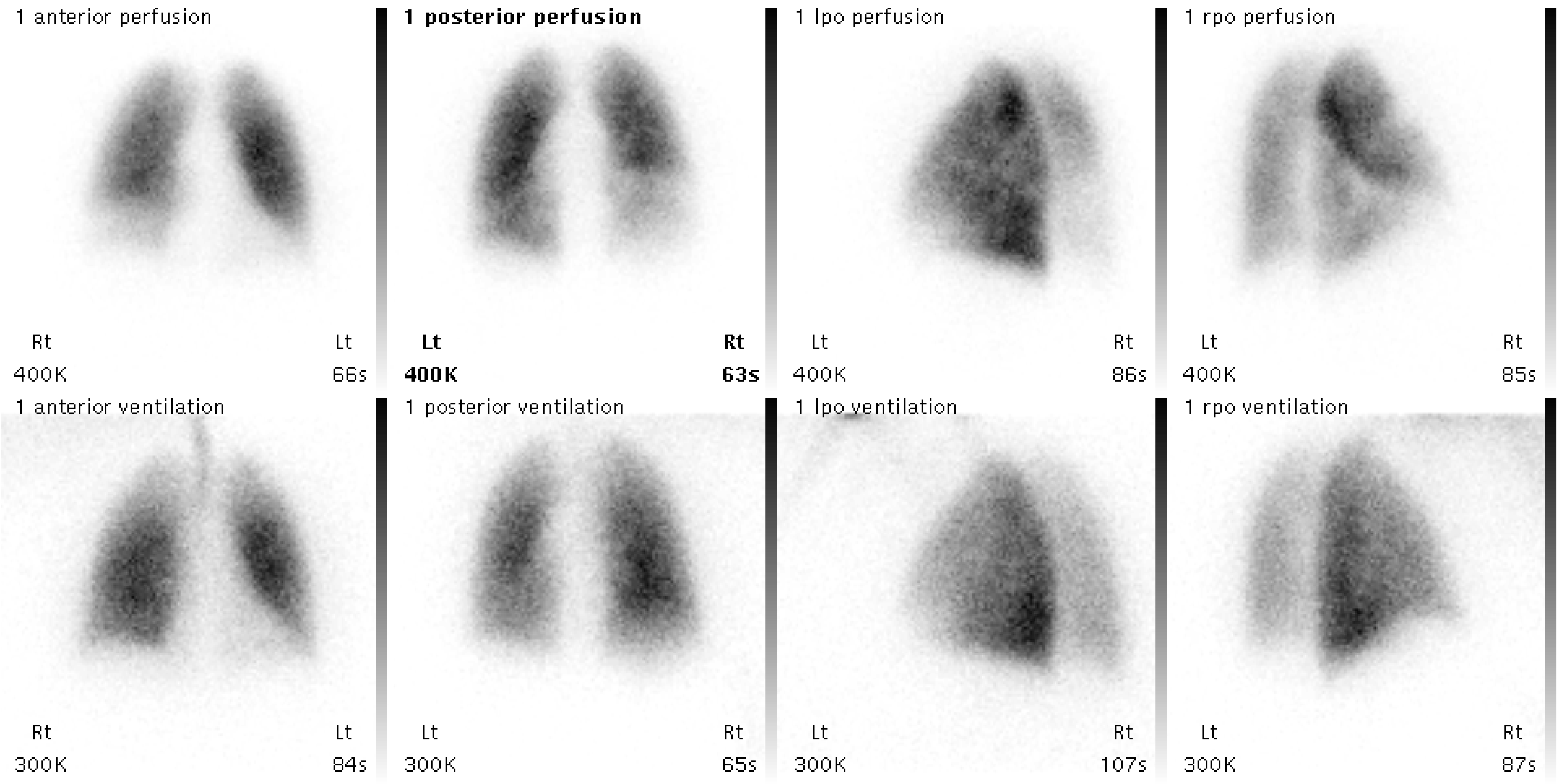
Ventilation-perfusion scan



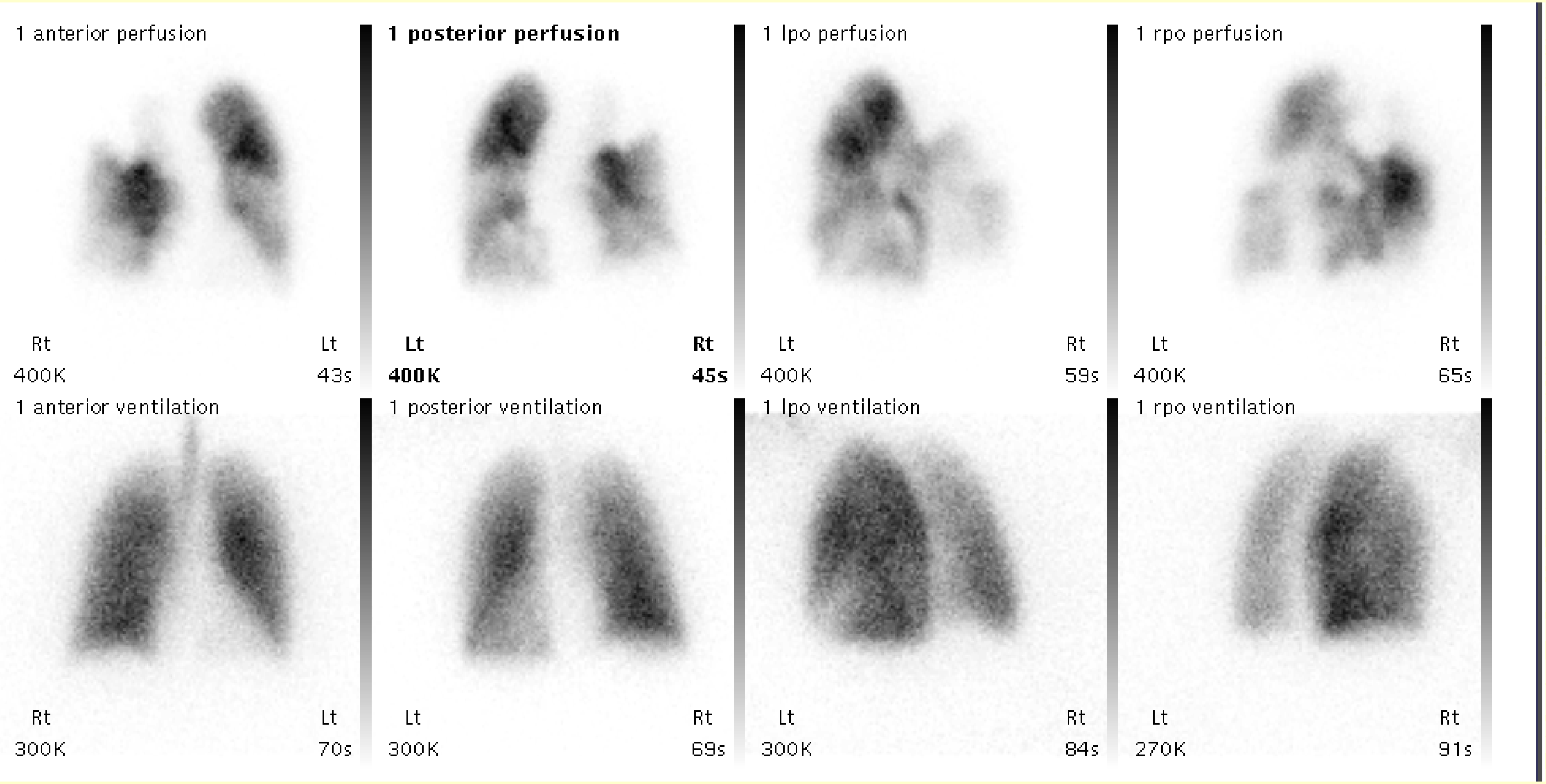
Normal ventilation-perfusion



Abnormal ventilation-perfusion
(LR lobe)

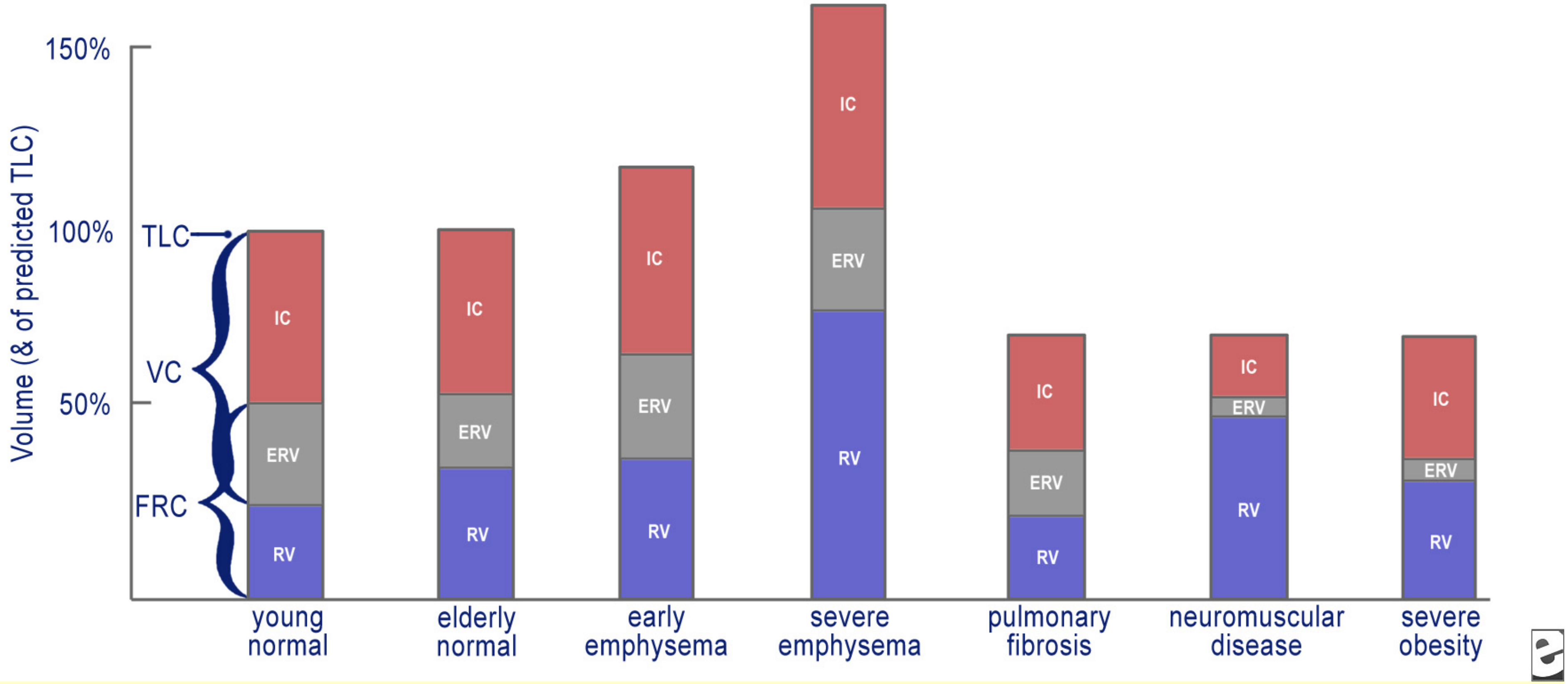


Abnormal ventilation-perfusion
(multiple perfusion defects)



Thank you !

Lung volumes in health and in disease



Total lung capacity (TLC)
Forced vital capacity (FVC)
Residual volume (RV)

Inspiratory capacity (IC)
Expiratory reserve volume (ERV)
Functional reserve capacity (FRC)