Pulmonary volumes and capacities

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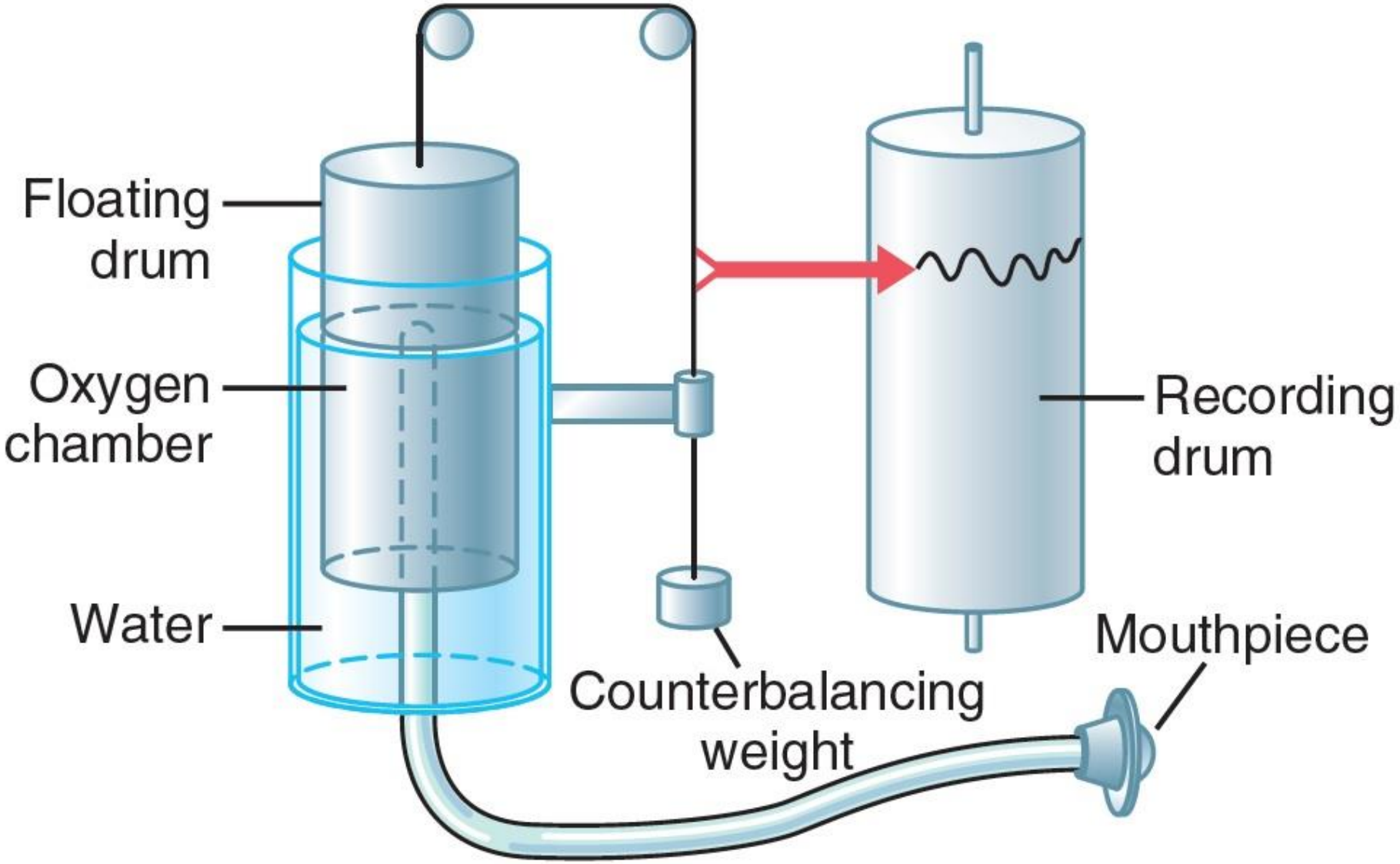
Lecture Objectives:

1. Define spirometry.
2. Describe the significance of the major volume and capacities that are recorded during normal function test.
3. Explain how spirometry (pulmonary function test) measures lung volumes and airflow in healthy individuals and in patients. And define FVC, FEV1 ($FEF_{25–75}$), and PEFR.
4. Describe the techniques used to determine the residual volume.
5. Explain forced expiratory volumes and differentiate between obstructive and restrictive respiratory dysfunction



A spirometer

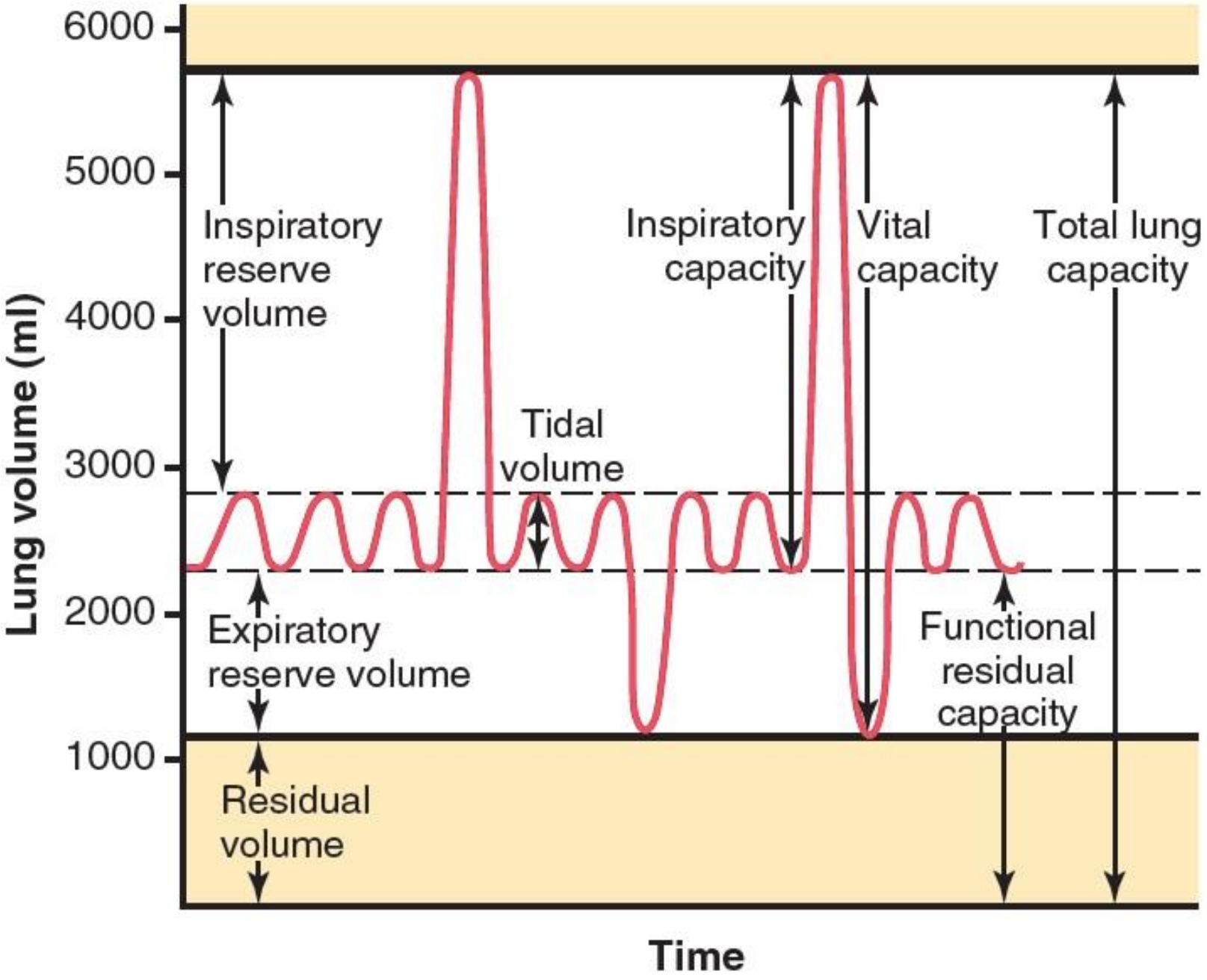
Spirometry:

def.; Is a technique used to study pulmonary ventilation by recording the volume movement of air into and out of the lungs. The recording from the spirometer is called ***spirogram***.

Pulmonary volumes:

Are ***four*** volumes, the sum of all equals the maximum volume to which the lungs can be expanded.

1. The **tidal volume** (V_T): is the volume of air inspired of expired with each normal breath; it is about 500 ml.
2. The **inspiratory reserve volume** (IRV): is the maximum extra volume of air that can be inspired over and above the normal tidal volume; it is about 3000 ml. The IRV may be invaded if the tidal volume must be increased as during exercise.
3. The **expiratory reserve volume** (ERV): is the maximum extra volume of air that can be expired by forced expiration after the end of a normal tidal expiration; it is about 1100-1300 ml. The ERV may be invaded when the tidal volume is increased as during exercise.
4. The **residual volume** (RV): is the volume of air remaining in the lungs after the most forceful expiration; it is 1200 ml. RV prevents complete collapse of the airways and alveoli. This volume can only leave the lungs if they collapse away from the chest wall, as in pneumothorax. (even then about 200 ml remains trapped)


6000
5000
4000
3000
2000
1000
Lung volume (ml)
Inspiratory reserve volume
Tidal volume
Expiratory reserve volume
Residual volume
Inspiratory capacity
Vital capacity
Total lung capacity
Functional residual capacity
Time

Pulmonary capacities:

Are combinations of two or more of the volumes together. There are ***four*** capacities.

1. The **inspiratory capacity** (IC): is the *tidal volume* + *inspiratory reserve volume* (IC = V_T + IRV); it is about 3500 ml.
2. The **functional residual capacity** (FRC): is the *expiratory reserve volume* + *residual volume* (FRC = ERV + RV). FRC is the amount of air that remains in the lungs at the end of normal expiration, it allows oxygenation of the blood between breaths; it is about 2300 ml. FRC falls with lying supine, obesity, pregnancy and anesthesia.
3. The **vital capacity** (VC): is the *inspiratory reserve volume* + *tidal volume* + *expiratory reserve volume*. It is the maximum amount of air a person can expel from the lungs after first filling the lungs to their maximum extent and then expiring to the maximum extent; it is about 4600 ml.

   VC = IRV + V_T + ERV

   VC = IC + ERV
4. The **total lung capacity** (TLC): is the *vital capacity* + *residual volume*. It is the maximum volume to which the lungs can be expanded with air; it is about 5800 ml.

   TLC = VC + RV

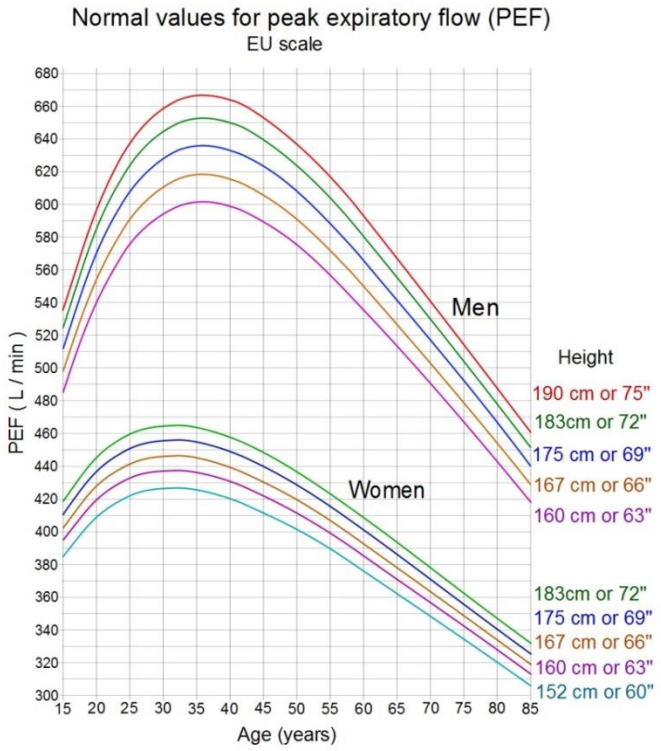
   TLC = IC + FRC

The Forced Vital Capacity (FVC):

- FVC is one of the most useful measurements to assess ventilatory function of the lungs.
- To measure FVC, the person inspires maximally and then exhales into the spirometer as forcefully, rapidly, and completely as possible.
- Two additional measurements can be obtained from the FVC spirogram.
  1. Forced expiratory volume of air exhaled in 1 second (**FEV_1**).
  2. Forced expiratory flow (**$FEF_{25–75}$**).
- FEV_1 has the least variability of the measurements obtained from a forced expiratory maneuver and is considered one of the most reliable spirometry measurements.
- FEV1 is usually presented as a percentage of FVC (i.e., FEV1/FVC × 100). Normally the FEV1/FVC ratio is 80%.
- $FEF_{25–75}$ has the greatest sensitivity in detecting early airflow obstruction. This measurement represents the expiratory flow rate over the middle half of the FVC (between 25% and 75%).
- Measurements of FVC,FEV1, FEV1/FVC ratio, and $FEF_{25–75}$ are used to detect obstructive and restrictive pulmonary disorders.

Peak Expiratory Flow Rate (PEFR):

- It is the volume of air forcefully expelled from the lungs in one quick exhalation. It is measured in liters/min.
- It is dependent upon factors such as sex, age and height. PEFR is typically higher in males than females and higher in taller patients.
- PEFR decreases with age from 30-40 years onwards.
- To interpret the significance of peak expiratory flow measurements, a comparison is made to reference (normal, predicted) values based on measurements taken from the general population.
- The highest of three readings is used as the recorded value of the Peak Expiratory Flow Rate.



- Asthma is the most common condition that affects peak flow. However, Chronic Obstructive Pulmonary Disease (COPD) that cause airway obstruction can also affect PEFR.
- Unlike spirometry that can be used to diagnose both obstructive and restrictive diseases, peak flow meter is used to detect obstructive lung diseases only.

Note:

1. Lung volumes and capacities are about 20-25% less in women than in men. They are also less in short people, people living at low altitudes, smokers, and non-athletes.
2. With ageing there a reduction in elastic recoil of the lungs and stiffening of the chest wall, which leads to a gradual increase in RV and FRC (ERV decreases) and a fall in VC with little change in TLC.
3. A. **Restrictive lung diseases (cause decreased ability to inspire)**; such as in Pneumonia, adult respiratory distress syndrome (ARDS), Tuberculosis, pulmonary fibrosis, Pleurisy, and diaphragm paralysis, all volumes and capacities are less than normal.

   B. **Obstructive lung diseases (cause difficult expiration)**; like asthma, chronic bronchitis, bronchiolitis, and emphysema, RV is increased (air trapping) and hence FRC. There is little change in IRV but the ERV and VC are often reduced. Both FVC and FEV_1 decrease as well.

Determination of functional residual capacity:

The functional residual capacity cannot be measured by spirometer because the air in the residual volume of the lungs cannot be expired into the spirometer. Measurement is achieved by helium dilution method (Helium is a gas which is neither produced nor reabsorbed by the body). The used formula;

$$FRC = \left(\frac{Ci_{He}}{Cf_{He}} - 1 \right) Vi_{spir}$$

Where:

Ci_{He} = initial concentration of He in the spirometer

Cf_{He} = final concentration of He in the spirometer

Vi_{spir} = initial volume of the spirometer

Minute respiratory volume (V_E):

Is the total amount of new air moved into the respiratory passages each minute. It is equal to the tidal volume (V_T) times the respiratory rate or frequency (f) which is 12-15 breaths/min; it is about 6-7.5 L/min. Hyperventilation is the term for having an increased minute volume.

$$V_E = V_T \times f$$

In restrictive lung diseases, the minute respiratory volume compensates for the shallow tidal volume by increasing the frequency of breathing.

Test Question:

Q. A 48-year-old patient undergoes a pulmonary function test. At which lung volume would his pleural pressure be most negative?

A. Residual volume.

B. Functional residual capacity.

C. End of tidal volume.

D. Total lung capacity.

E. Middle of forced vital capacity.