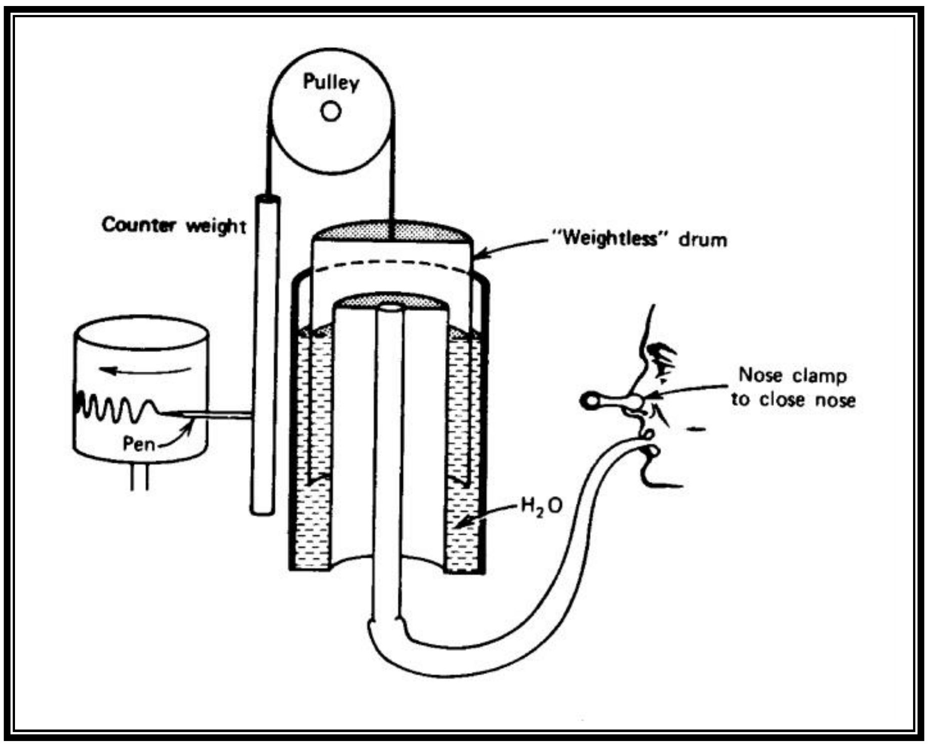
University AL-Qadisiyah/College of Medicine
Dept. of Physiology and Medical Physics, Medical Physics
Lecturer: Assist prof. Dr. Khalid Ibrahim

Chapter Seven: Physics of the lungs and breathing/P2

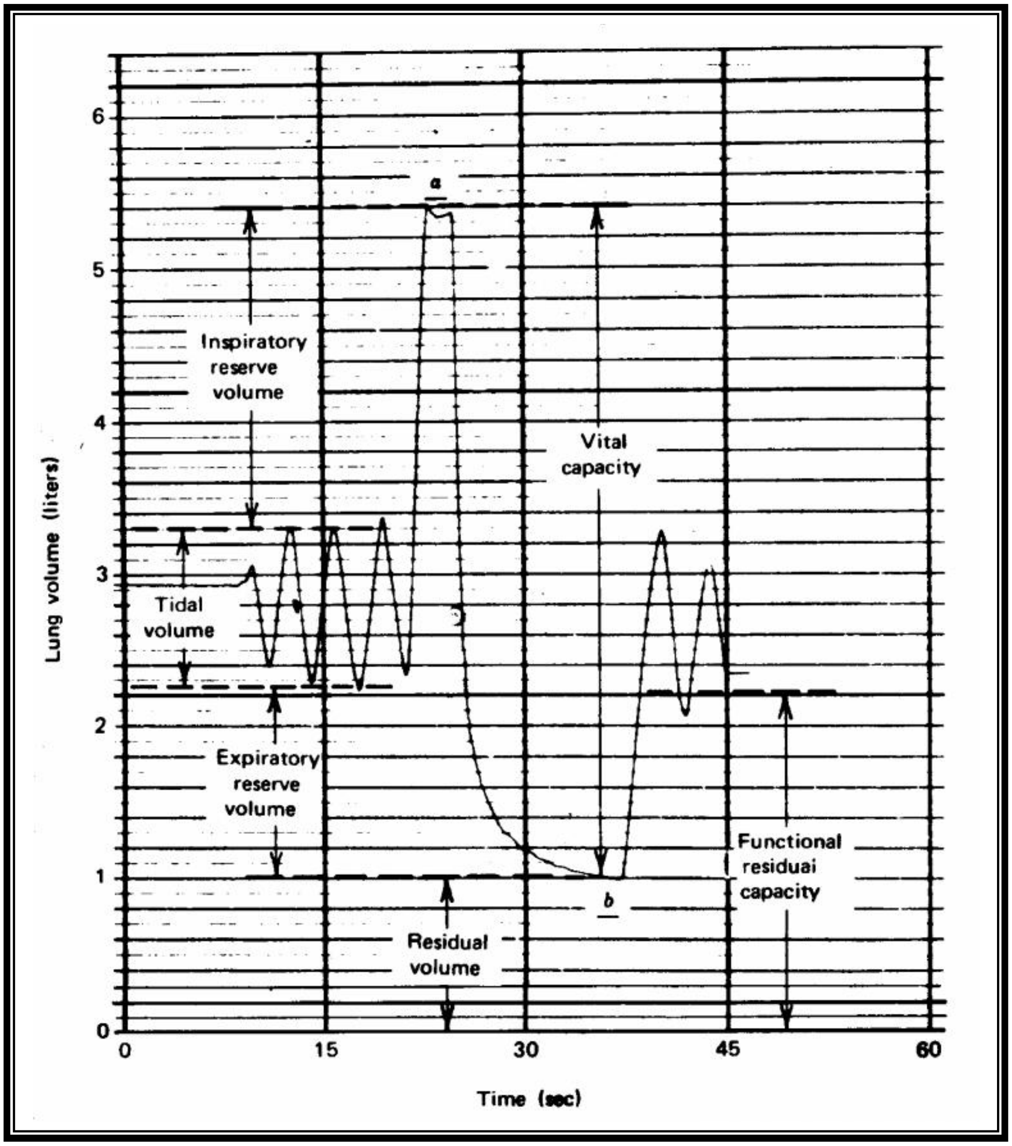
4. Measurement of lung volumes

Spirometer: Simple instruments, is used to measure air flow into and out of the lungs and recorded it on a graph of volume versus time. As shown in the figure below:



During normal breathing:

1. **Tidal volume:**
   Is the volume of air breathed, and it‘s about 500 cm^3 of air with each breath at rest. During heavy exercise, the tidal volume is considerably larger.
2. **Inspiratory Reserve Volume:**
   Is the max. volume of air which can be inspired after completing a normal tidal inspiration.



3. **Expiratory Reserve Volume**:
   Is the max. volume of air which can be expired after a normal tidal expiration.
4. **Functional residual capacity (FRC)**:
   Is the volume of air remaining in the lungs after a normal expiration.
5. **The vital capacity**:
   Is the max. volume of air which can be expired from the lungs by forceful effort following a max. inspiration.
6. **The residual volume**:
   Is the volume of air which remains in the lungs after a maximal expiration (~ 1 liter for adult).

FRC = Residual volume + Expiratory Reserve volume.

7. **Total lung capacity (TLC):**
   Is the volume of air contained in the lungs after maximal inspiration ~ (5400 ml in adult man).

   TLC =Vital capacity + Residual volume.

The clinical tests that can be done with spirometer are:

1. **Respiratory minute volume:**
   The amount of air breathed in 1 min.
2. **Maximum voluntary ventilation**:
   The max. volume of air that can be breathed in 15 sec.

The Dead spaces:

The spaces at which air does not provide O_2 to the blood. There are two dead spaces:

1. **Anatomical dead spaces:**
   The volume of the airways between the mouth, nose, trachea and bronchi. It is called dead spaces because the air in these spaces is not exposed to the blood in the pulmonary capillaries. Normally it is about 150 cm^3.

2. **Physiological dead spaces:**
   In some diseases some of the alveolar capillaries are not perfused with blood and the O_2 is not absorbed in these alveoli.

5. Pressure- Airflow- Volume relationships of the lungs:

The pressure, airflow, and volume relationships of the lungs during tidal breathing for a normal individuals and for a patient with a narrowed airway are shown in the figure (7.9)

Note: The increased pressure and decreased flow rates during expiration due to the narrowed airway (in the patients).

The pressure difference needed to cause air to flow into or out of the lungs of a healthy individual is quite small.

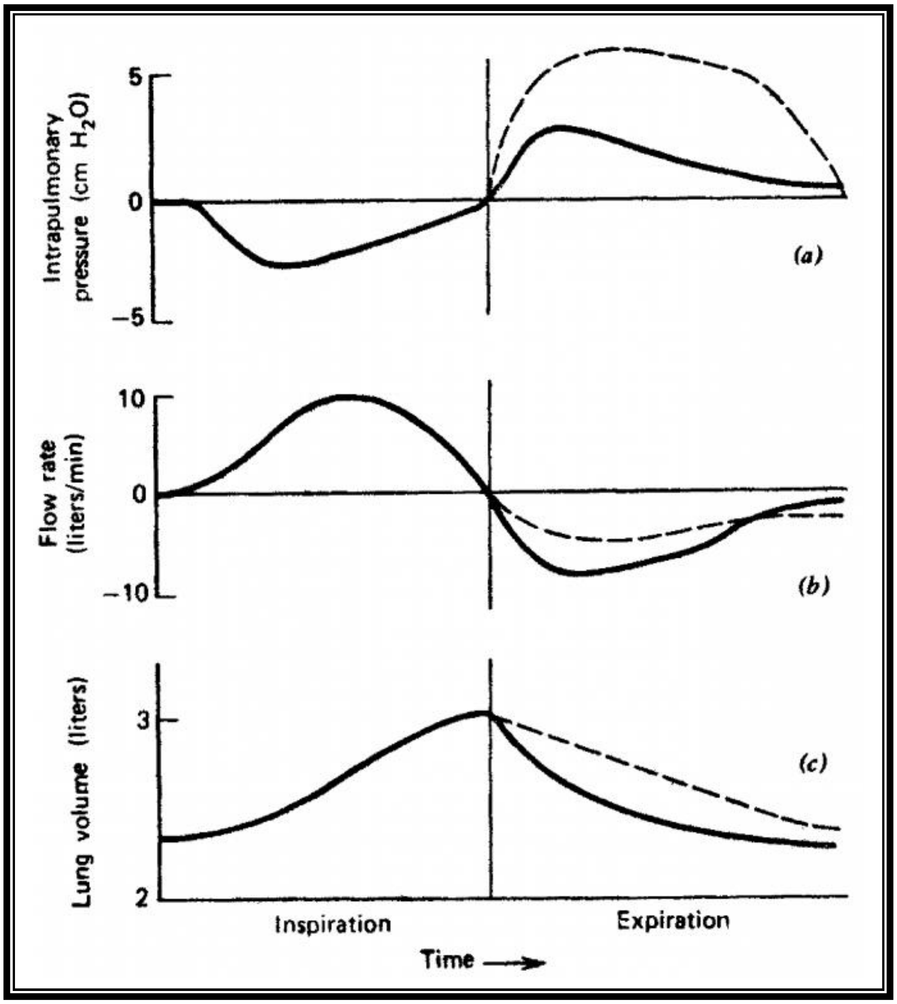


Fig.(7.9): a- Typical pressure. b- flow rates. c- lung volumes during quiet respiration for a normal individual (solid line) and a patient with a narrowed airway (dashed line).

6. **Compliance**:

It is an important physical characteristics of the lungs. Its change in volume produced by a small change in pressure.

$$C = \Delta V/\Delta P$$

It is obtained from the slope of the combined curve, and gives the compliance of the lung and chest system.

1. Unit of compliance: $C = \Delta V/\Delta P \longrightarrow$ liter/cmH_2O

2. In normal adults is in the range of (0.18 to 0.27) liter/ cmH_2O

- A stiff (fibrotic) lung has a small change in volume for a larger change and thus it has a low compliance.

C = (Small change in volume / large change in pressure) $\longrightarrow$ low compliance

7. Physics of the alveoli:

The alveoli like millions of small interconnected bubbles, they have a natural tendency to get smaller due to the surface tension of unique fluid lining. This lining called (Surfactant).

To understand the physics of the alveoli we have to understand the physics of the bubbles.
The pressure inside a bubble is inversely proportional to the radius (R) and directly proportional to the surface tension (γ). See figure (7.15).

$$\mathbf{P = 4\,\gamma/R}$$

This relation called (Laplace‘s law).
There is a tendency for the smaller alveoli to collapse. The condition that results when a sizable number collapse is called (atelectasis).
But, the reason for the most of the alveoli don‘t collapse is related to the unique surface tension properties of surfactant.

What is the surface tension?

$$\gamma = \text{force / length}$$

γ = for water = 72 dyne /cm
γ = for plasma = 40 – 50 dyne/cm
γ = for detergent solution = 25 – 45 dyne/ cm

8. Airway resistance

1. We can breathe in more rapidly than we can breath out.
2. During inspiration the forces on the airways tend to open them further.
3. During expiration the forces tend to close the airways and thus restrict airflow.
4. Patients with obstructive airways disease (Such as asthma or emphysema) will sever from:
   a- Increased effort to breathe out.
   b- Decrease the flow rate considerably.

c- Retaining a large amount of air in the lungs.

5. The flow of air in the lungs is analogous to the flow of current in an electrical circuit (Ohm's law).

$$R = V/I \longrightarrow \text{Volt / Amp.}$$

$R_g = \Delta P/(\Delta V/\Delta t)$ = pressure difference / flow rate = cmH_2O/(Liter/sec.)

R_g: Airway resistance

6. In typical adults $R_g = 3.3\ cmH_2O$/(liter/sec).

7. R_g depends on:
   a- The dimensions of the airway.
   b- The viscosity of the gas.

8. Most of the resistance is in the upper airway passages.
   a- In nasal part ~ 50% R_g
   b- In upper airways ~ 20% R_g
   c- In the terminal airways ~ $<$ 10 % R_g (Bronchioles and alveoli).

9. Time constant (τ):

a- Time constant for the lung is = R_g x Compliance

$\tau = [\Delta P/(\Delta V/\Delta t)] \times [\Delta V/\Delta P]$

τ unit is sec.

b- If one part of the lung has a larger τ than other parts that mean; it will not get it's share of air. And that part of the lung will be poorly ventilated.