Physiology of the Respiratory system Lecture 1

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Divisions

- **The respiratory system is divided anatomically into:-**

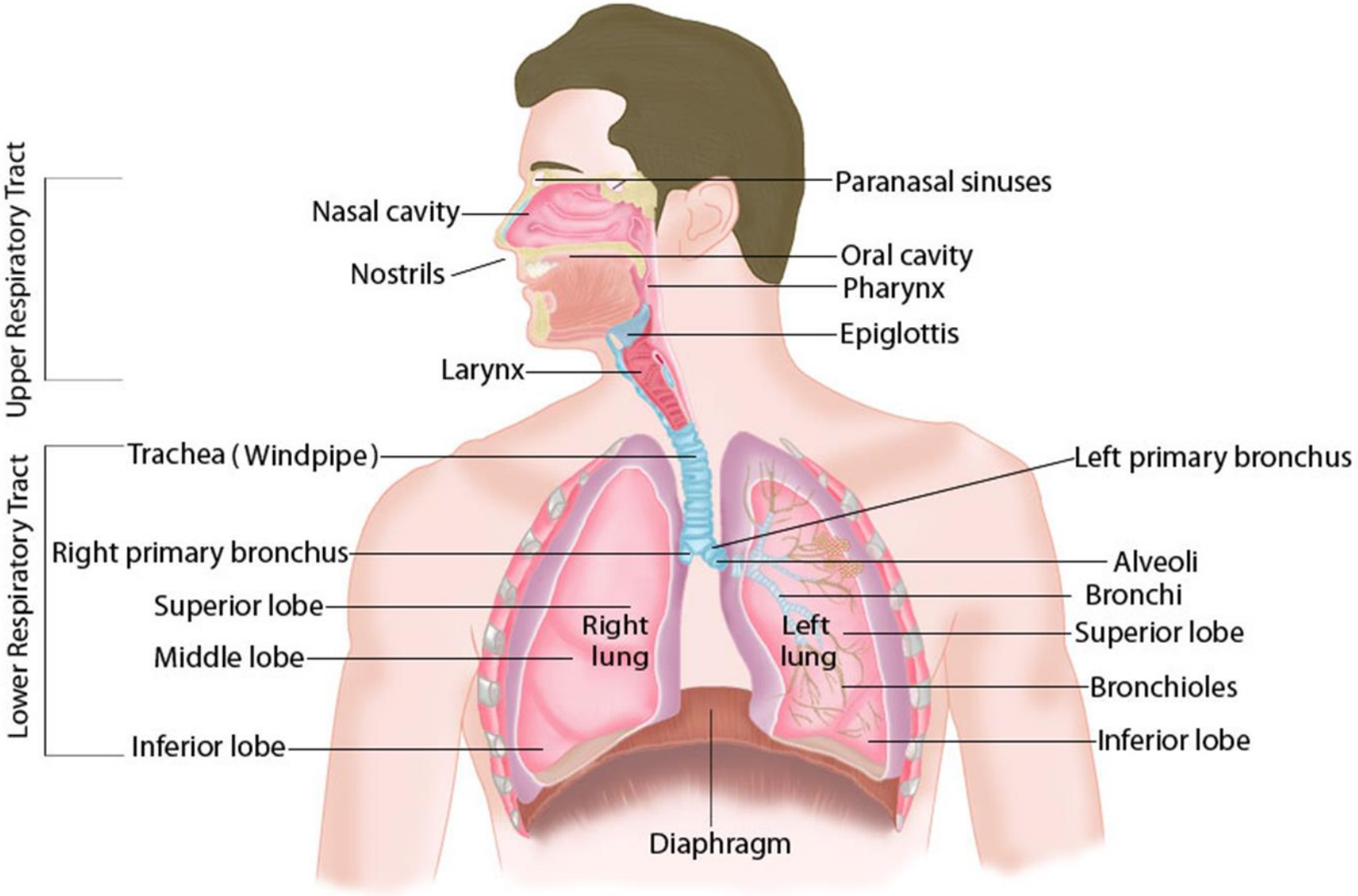
- **Upper respiratory tract (UPR)**

✓ Include all structure outside the thoracic cage, (the chest). These are the nasal cavity, the pharynx, larynx, &upper part of trachea.

- **Lower respiratory tract (LRT)**

✓ Include all structure inside the thoracic cavity. These are the lower part of trachea, bronchi, bronchioles, alveolar sacs (including alveolar ducts& alveoli).

Anatomic division of the respiratory tract



- **The URT characterized by the presence of:**

✓ **Hair (within the nose),**

✓ **Ciliated epithelium**,

✓ **Mucus secreting cells&**

✓ **Rich blood supply.**

- **Evaporation of water** from the surface of the respiratory mucosa moistens & equilibrates temperature of inspired air with that of the body; thus making inspired air suitable for gas exchange in the distal parts of the lung.

- **The respiratory system is divided according to major function:-**

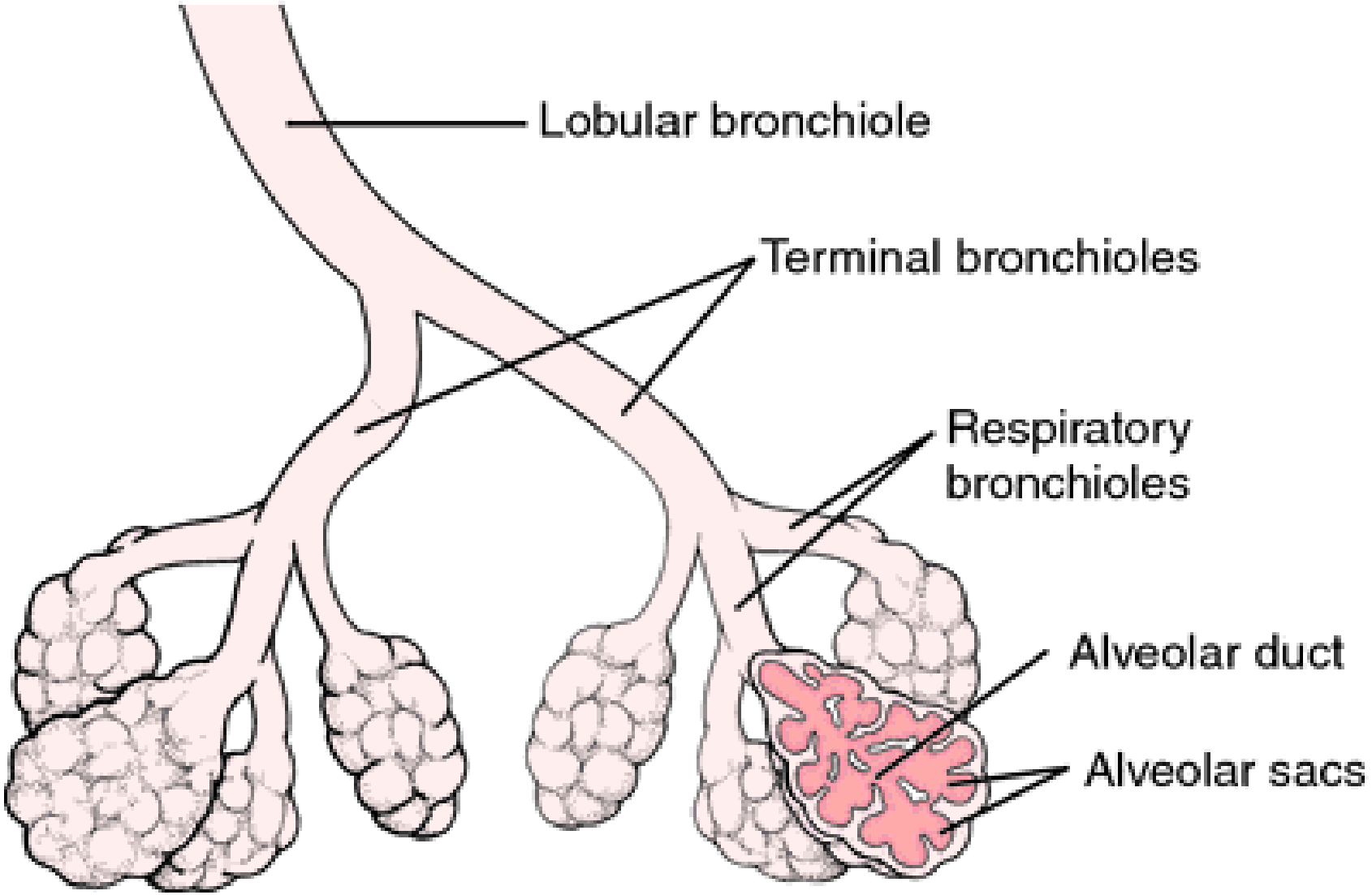
1.For conduction of air to the lower zone:

- Including the nasal cavity, pharynx, larynx, trachea, bronchi& bronchioles (up to terminal bronchioles)

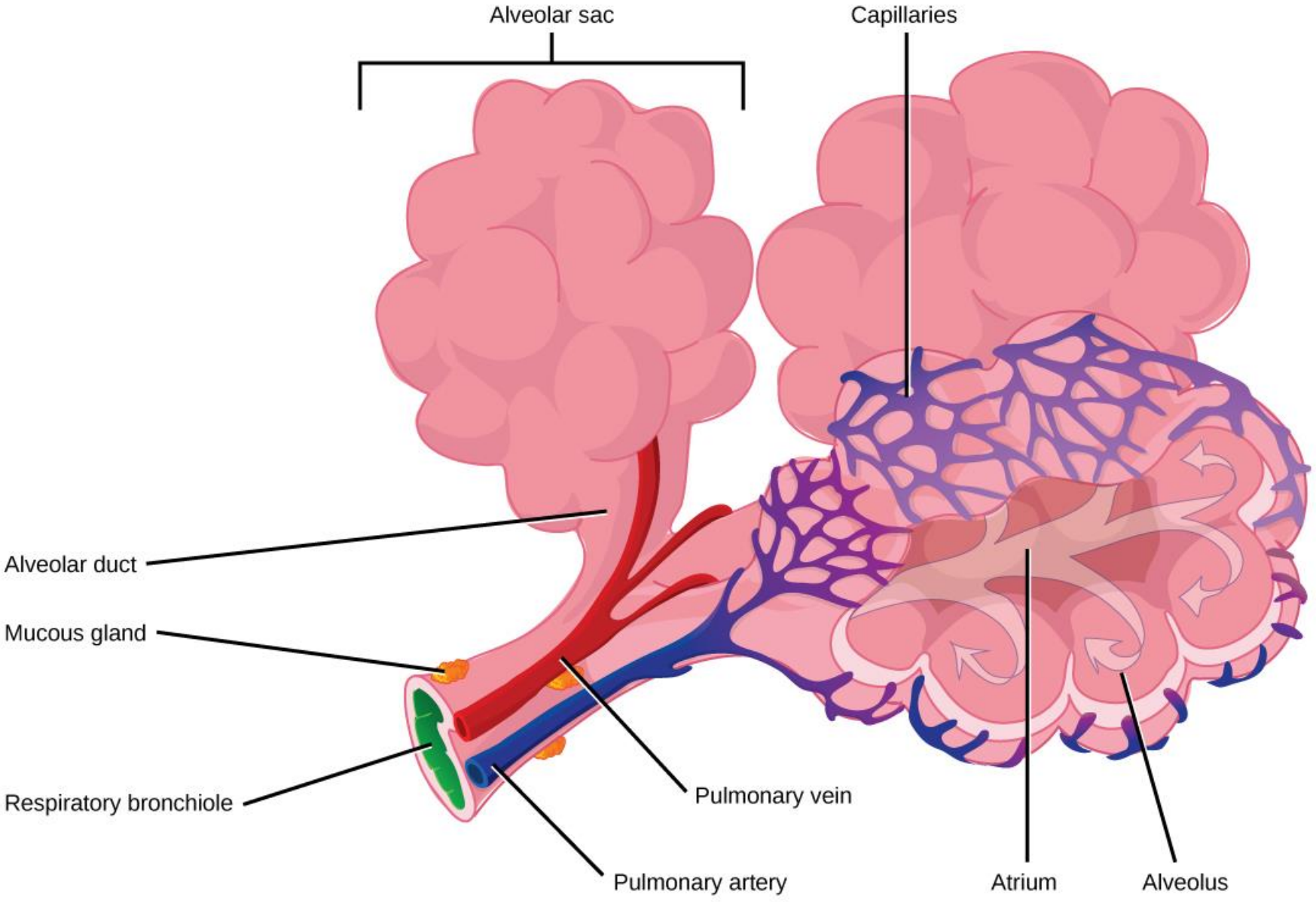
1.Respiratory zone:

- For gas exchange.
  - Include the respiratory bronchioles& alveolar sacs (alveolar ducts& alveoli)

Terminal bronchioles and respiratory bronchioles



Respiratory bronchioles and alveolar sacs



Important anatomical point

Tracheobronchial tree:

- Formed by about 23 divisions
- The **first 16 divisions** (starting from the trachea to the terminal bronchioles), form the **conducting zone** whereas the other **7 divisions** (starting from the respiratory bronchioles to the alveoli) form the **respiratory zone**.
- The trachea& bronchi have cartilage in their walls but little smooth muscles while the bronchioles have smooth muscle in their walls but no cartilage.

The cartilages:

1. Support the wall of trachea& large bronchi&
2. Prevent their collapse when the pressure inside them decreases (as occur during inspiration).

- This function is lost in the case of **tracheomalacia**; that's why the patient suffers from an inspiratory sound due to URT obstruction (stridor).

- These multiple divisions greatly increase the total cross-sectional area of the airways, from **2.5 cm^2** in the trachea to **11.800 cm^2** in the alveoli (respiratory bronchioles).

- Consequently, the velocity of air flow in the small airways declines to very low values.

- The alveoli are surrounded by pulmonary capillaries.
- In most areas, air and blood are separated only by the alveolar epithelium and the capillary endothelium, so they are about **0.5 µm** apart.
- There are **300 million alveoli** in humans, and
- the total area of the alveolar walls in contact with capillaries in both lungs is about **70 m^2**.

The lungs

- The lungs (Rt & Lt) found within the thoracic cavity, protected by rib cage.
- Each lung consists of:

✓ Air ways

✓ Parenchymal tissue supporting air ways,

✓ Blood vessels,

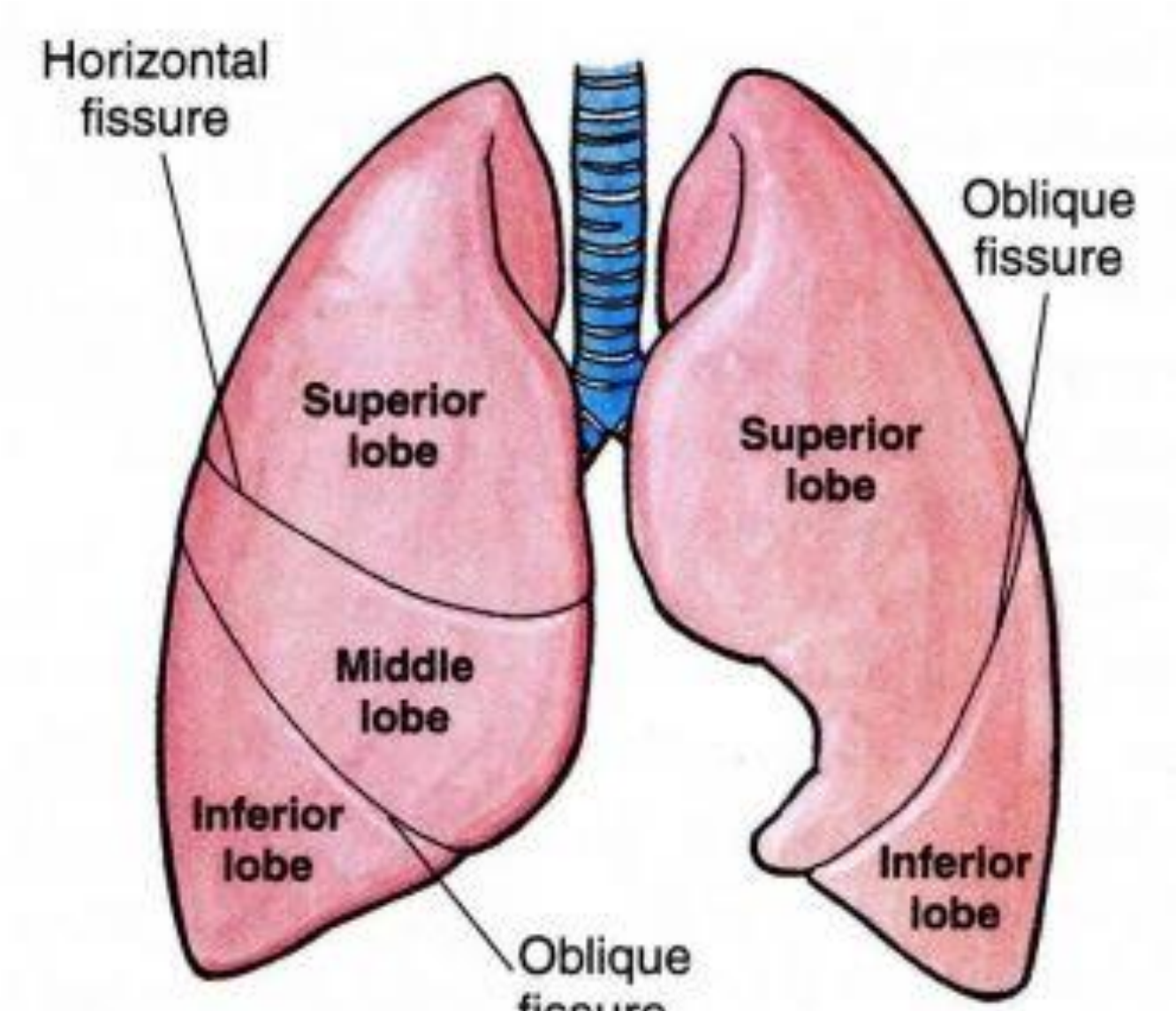
✓ Nerves &

✓ Lymphatic.

- Each lung is divided by horizontal& oblique fissures, into lobes.

- The right lung (consisting of three lobes) is larger than the left lung (consisting of two lobes due to the presence of the heart).

Lung lobes


Horizontal fissure
Oblique fissure
Superior lobe
Middle lobe
Inferior lobe
Superior lobe
Inferior lobe
Oblique

- The lungs provide a surface for gas exchange.

- LRT disease mainly affects the lungs. They include: inflammation of the lung (pneumonia), acute air way obstruction (asthma), chronic air way obstruction “COPD” (emphysema), lung fibrosis …. Etc

The pleural cavity

- Each lung is covered by a membrane that is attached to its outer surface (visceral pleura). The membrane continues to line the inner surface of the chest wall (the parietal pleura).
- **The space** formed between the visceral& parietal pleura is called pleural cavity.

The pleural cavity contain few milliliters of fluid that act as:

1. lubricant.
2. It allow easy expansion of lungs&
3. Resist separation of the two membranes therefore normally, no cavity is actually present.

Functions of the lungs

- Provide oxygen to the tissues.
- Eliminate Carbone dioxide from the tissues.
- Participate in the regulation of blood PH.

  - -Those 3 functions are the main functions of the respiratory system.

Other function of the respiratory system:-

A. Participate in regulation of the body temperature. Hyperventilation increase heat loss by evaporation from mucous membranes.

B. Has some important metabolic functions including:-

1. Conversion of angiotensin I to angiotensin II (by angiotensin converting enzyme (ACE) which is produced by the pulmonary endothelium.
2. Inactivation of certain vasoactive substances like bradykinin (also by ACE).
3. Break down of arachidonic acid metabolites like prostaglandins& leukotrienes.
4. Synthesis of surfactant.

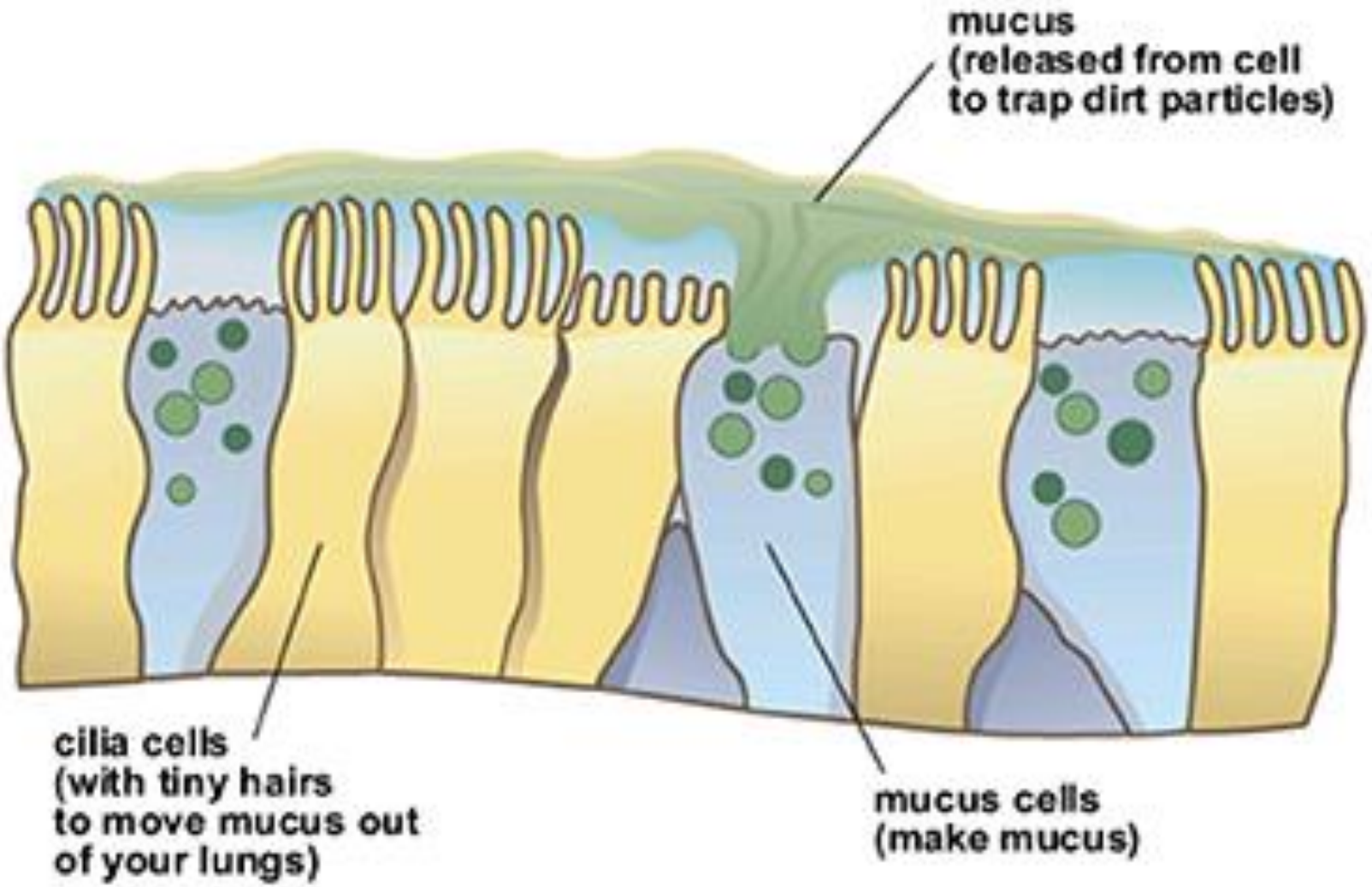
C. Has many important defense mechanism:-

1.Hair within nose for filtration of air (remove particle) 10μm in diameter

2.Mucus on the surface of respiratory epithelium for trapping of smaller particle (2_10 μm in diameter).

3.Cilia on cells for transporting of trapped particles upward towards nasopharynx to be swallowed or coughed out (called mucociliary clearance).

4.Cough or sneezing reflex for ejection of unwanted substances through the mouth to outside.



Airway Walls

Ventilation

Definitions:-

- ✓ Ventilation is the process of getting air into& out of the lungs during breathing. It's always **adjusted** to meet metabolic demands of the body (provide sufficient oxygen& to eliminate excess CO_2).
- ✓ **Hyperventilation** refers to ventilation in excess metabolic demand of the tissues. It's usually result in hypocapnia (↓ PCO_2).
- ✓ **Hypoventilation** refers to ventilation less than metabolic demands of the tissues. It's usually result in hypercapania (high or ↑PCO_2).

Mechanism of ventilation:-

- Air moves into& out of the lungs due to pressure gradient (when atmospheric pressure is higher than intrapulmonary pressure, its gets into the lungs (inspiration);& when atmospheric pressure is lower than intrapulmonary pressure, it gets out of the lungs (expiration).

- According to **Boyle's law**, there is an inverse relationship between the pressure of gases& volume.

- Therefore, there is an inverse relationship between the pressure of gasses within the lungs& their size.

- Inspiration result in inflation of the lungs& therefore in reduction in intrapulmonary pressure (IPP), whereas expiration does the reverse.
- During normal inspiration →IPP is -1mmHg.
- During normal expiration →IPP is +1mmHg.
- At the end of maximum inspiration →IPP is -30mmHg.
- At the end of maximum expiration→ IPP is +50mmHg.

Remembers:-

- The atmospheric pressure is 760mmHg.
- Values of IPP indicate deference from the atmospheric pressure.
- A value of -1mmHg indicate a pressure less than atmospheric pressure by 1 (i.e 759mmHg), whereas a value of +1 indicate a pressure higher than atmospheric pressure by 1 (i.e 761mmHg).

- Closure of glottis at upper part of the larynx isolates the respiratory system from the atmosphere. Therefore there is no equilibrium between IPP& atmospheric pressure.
- Opening of glottis allows equilibrium of IPP with atmospheric pressure. That's why IPP at end of normal inspiratory and expiratory phases equal to zero (i.e. 760mmHg similar to atmospheric pressure).

- **When the glottis is open** and no air is flowing into or out of the lungs, the pressures in all parts of the respiratory tree, all the way to the alveoli, are equal to atmospheric pressure, which is considered to be zero reference pressure in the airways—that is zero centimeters water pressure. (i.e. 760mmHg similar to atmospheric pressure).

Intra pleural pressure (IPLP)

- The intra pleural pressure undergoes similar change; however, opening& closure of the glottis don’t change its values.
- During normal inspiration →IPLP is -6mmHg.
- During normal expiration →IPLP is -2.5mmHg.
- At end of maximum inspiration →IPLP is -30mmHg.
- At end of maximum expiration → IPLP>+50mmHg.

- **Remember** that intra pleural pressure is sub atmospheric (-ve) during normal inspiration& expiration whereas IPP is negative during inspiration& positive during expiration.

- Negativity of intra pleural pressure is explained by the tendency of the lung& chest wall to **recoil** into opposite directions (the lung tend to recoil inward due to its elastic properties, whereas the chest tend to recoil outward due to presence of the ribs).

Fluid in the Pleural Cavity

- When the lungs expand and contract during normal breathing, they slide back and forth within the pleural cavity.

- To facilitate this, a thin layer of mucoid fluid lies between the parietal and visceral pleurae.

- The pleural membrane is a porous, mesenchymal, serous membrane through which small amounts of interstitial fluid transudate continually into the pleural space.

- These fluids carry with them tissue proteins, giving the pleural fluid a mucoid characteristic, which is what allows extremely easy slippage of the moving lungs.

- The total amount of fluid in each pleural cavity is normally slight, only a few milliliters.

Whenever the quantity becomes more than enough being flowing in the pleural cavity, the excess fluid is pumped away by lymphatic vessels opening directly from the pleural cavity into **(1)** the mediastinum, **(2)** the superior surface of the diaphragm, and **(3)** the lateral surfaces of the parietal pleura.

Therefore, the *pleural space*—the space between the parietal and visceral pleurae—is called a ***potential space*** because it normally is so narrow that it is not obviously a physical space.

“Negative Pressure” in Pleural Fluid

- A negative force is always required on the outside of the lungs to keep the lungs expanded.
- This is provided by negative pressure in the normal pleural space.
- **The basic cause** of this negative pressure is pumping of fluid from the space by the lymphatics.

- Because the normal collapse tendency of the lungs is about -4 mm Hg, the pleural fluid pressure must always be at least as negative as -4 mm Hg to keep the lungs expanded.
- Actual measurements have shown that the pressure is usually about –7 mm Hg, which is a few millimeters of mercury more negative than the collapse pressure of the lungs.

Mechanism of inspiration:-

- Contraction of inspiratory muscles.
- Expansion of the chest.
- Reduction of intra pleural pressure.
- Expansion of the lungs.
- Reduction of intra pulmonary pressure.
- Air move into the lungs.

✓ **Inspiration is an active process** because it involves the contraction of inspiratory muscles.

The inspiratory muscles can be grouped into:-

Inspiratory muscles working at rest & during exercise

1)The diaphragm

- Responsible for 75% of inspiration.
- Descend down during contraction (1.5-7cm). This increase the vertical diameter of the chest.
- Supplied by phrenic nerve (C4).
- Consist of central tendon, costal fibers, & crural fibers.

2)The external intercostal muscles

- Contraction causes expansion of the chest by increase the anteroposterior& transverse diameter of the chest.

Accessory inspiratory muscles working during forced inspiration only:-

- **S**calene.
- **S**ternocleidomastoid. (3 S and 1 T)
- **S**erratus anterior.
- Trapezius.

Mechanism of expiration:-

- Relaxation of inspiratory muscles.
- Increase intra pleural pressure.
- Recoil of the lungs to expiratory position.
- Increased intra alveolar pressure.
- Air moves out of the lungs.

- ✓ **Expiration at rest is passive process** since it doesn’t involve contraction of any expiratory muscle.
- ✓ However forced expiration require the action of the following muscles that decrease the size of the chest:-
- Internal intercostal muscles.
- Abdominal muscles.

Volume& capacities measured by spirometer

- **Tidal Volume (TV):-** volume of the air inspired or expired each breath it equal (0.5L) in adult male& female at rest.
- **Inspiratory reserve Volume (IRV):-**volume of air inspired by maximum inspiratory effort following tidal inspiration.it equal (3L) in adult male& 1.9L in adult female.
- **Inspiratory Capacity (IC):-** volume of air inspired by maximum inspiratory effort following tidal expiration. It equal (TV+IRV).
- **Expiratory reserve Volume (ERV):-**volume of air expired by maximum expiratory effort following tidal expiration. It equal (1L) in adult male& (0.7L) in adult female.

- **Vital Capacity (VC):-** volume of air expired by maximum expiration following maximum inspiration. (=IRV+ TV+ ERV) or (IC+ ERV).Normal values: about (5L) in adult male& (4L) in adult female.

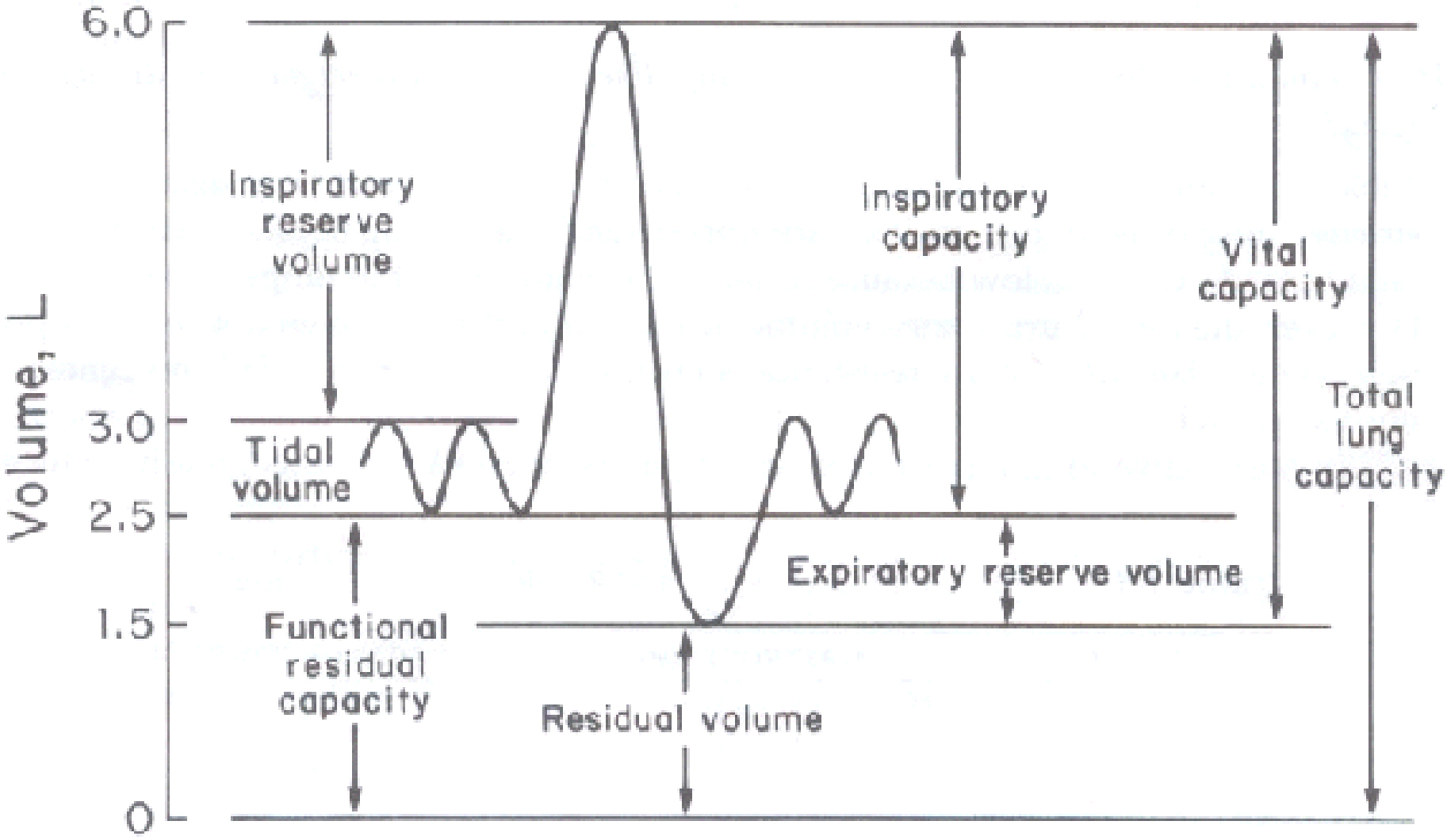
✓ Like other lung volumes, it differs according to age, gender, body size (weight& height), position (higher during standing), & ethnic background (higher Western population than African once).

- ✓ It’s an important index of disease. For this reason, it’s usually measured to diagnose certain respiratory problems.
- ✓ During measurement, the subject is asked to inspire air maximally& then to expire maximally into the mouth piece of spirometer.
- ✓ When the subject is asked to expire forcefully& as quickly as possible, the measured volume is called Forced Vital Capacity (FVC).
- ✓ The (FVC) is an important parameter in chest medicine.

- **Forced Vital Capacity (FVC):-** is volume of air expired forcefully by maximum expiration following maximum inspiration.

- ✓ Expiration normally takes (4_6) seconds. Forced expiratory time that takes longer than 6 seconds indicate air way obstruction.
- ✓ The volume of air expired during the 1^{St} second of the FVC is called forced expiratory volume in the 1^{st} second (FEV_1). It equal more than 3 quarter of the FVC (i.e. more than 75%). For example, when the FVC is 5L the FEV_1 is about 4L. (i.e. FEV_1/FVC ratio is 80%).
- ✓ The values of FEV_1& the FVC can be measured by vital graph. The device provides FVC& FEV_1 values on graph paper in the Y-axis, whereas X-axis represents time in seconds.

Volume& capacities measured by spirometer



Spirometry(FEV_1/FVC)

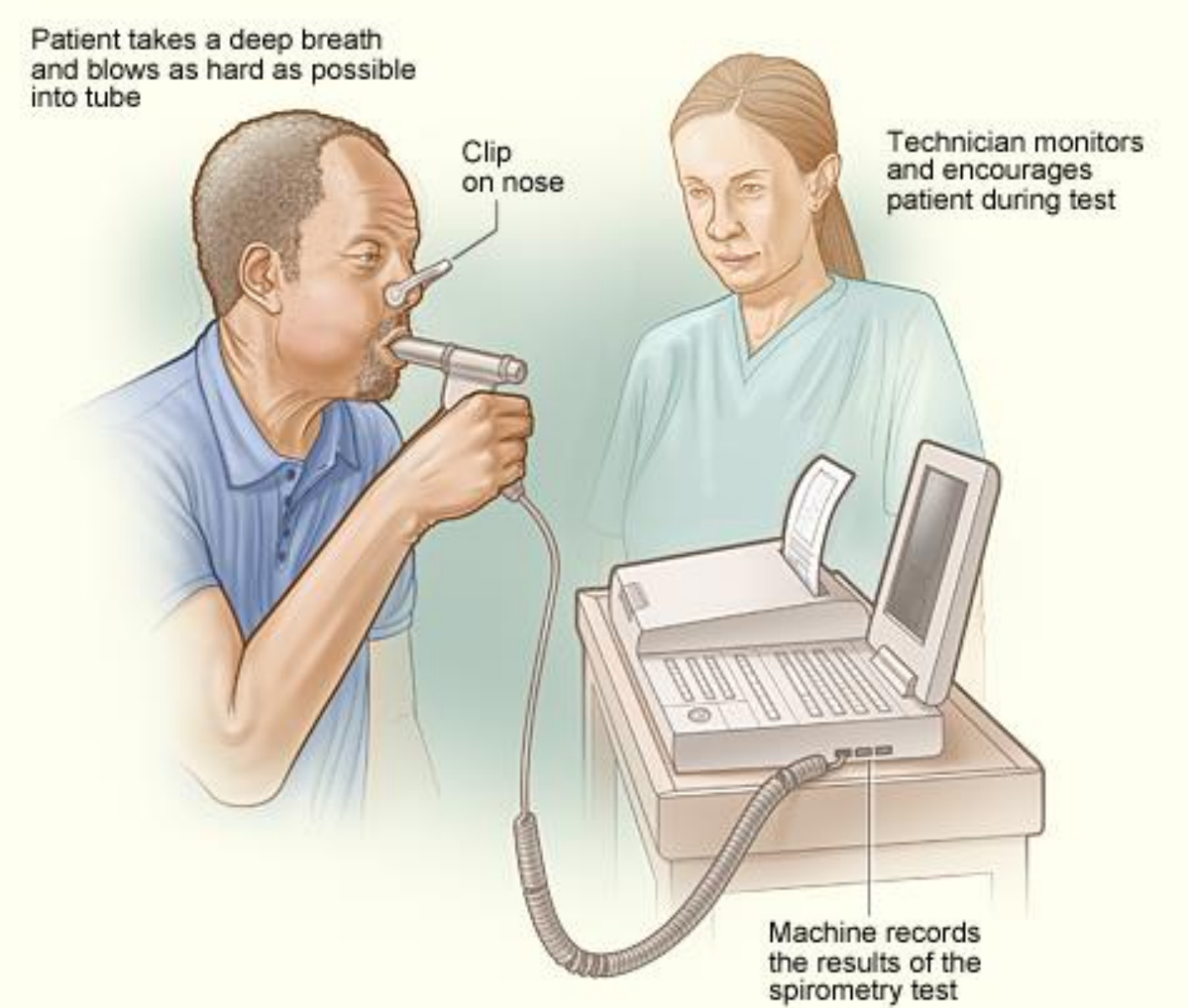
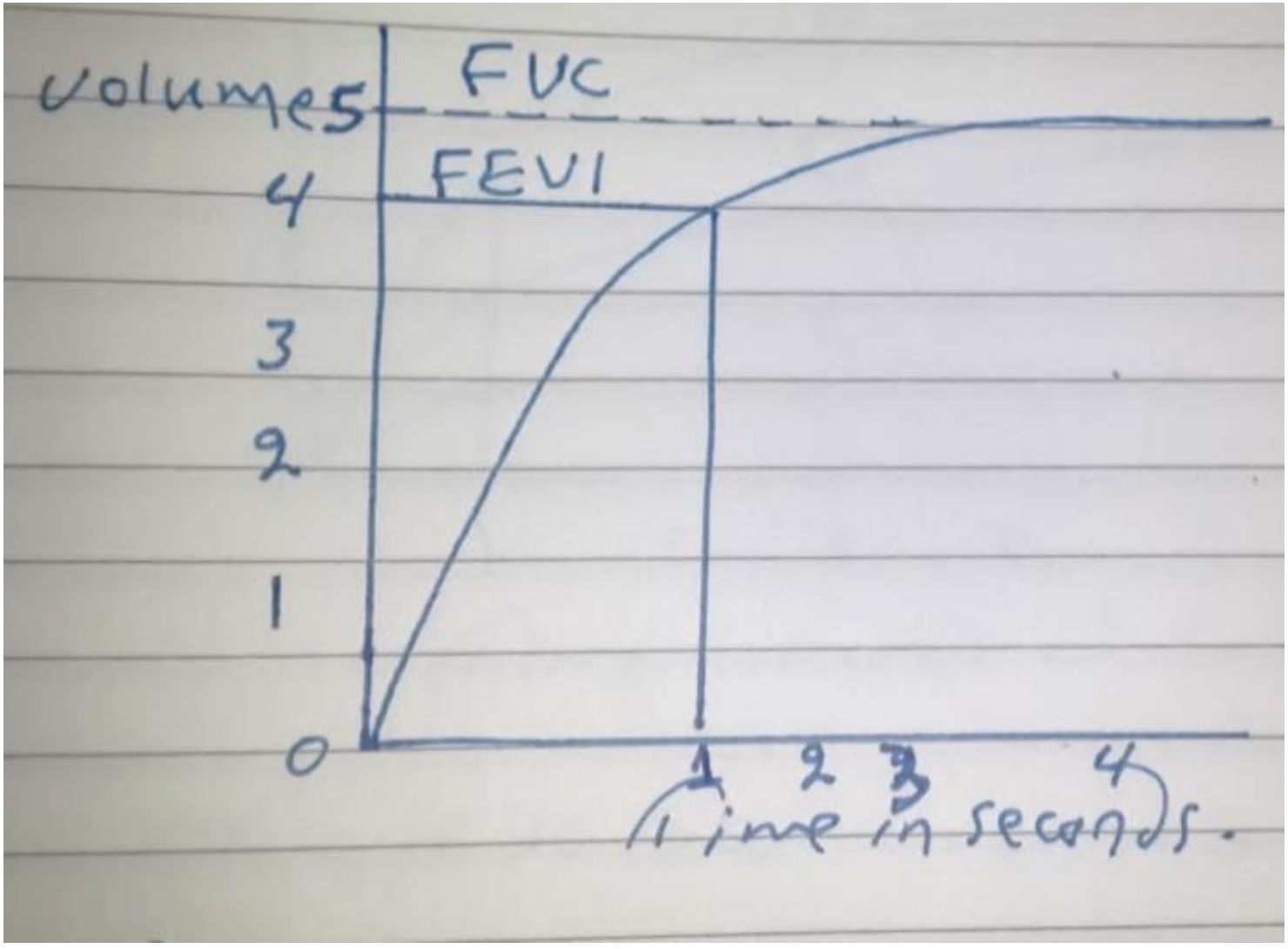


Figure one: FVC and FEV1 (Y axis) plotted against time (X axis)



- ✓ The FEV_1 /FVC ratio is usually measured to differentiate between obstructive& restrictive lung diseases.
- ✓ A normal ratio is about 80%.
- ✓ In obstructive lung disease (in which FEV_1 is lower than normal the ratio is less than 75%, example asthma, emphysema& chronic bronchitis).
- ✓ In restrictive lung disease (in which both FEV_1& FVC are lower than normal), the ratio is normal or increased (up to 100%) e.g. Lung fibrosis& lung collapse.
- ✓ In combined problems (obstructive& restrictive problems), all the parameters are lower than normal (i.e. low FEV_1, FVC& FEV_1/FVC ratio) e.g. asthmatic patient with lung fibrosis

- **Remember that** Remember when FEV_1 =5L and the FVC=5L; the FEV_1/FVC ratio=100%.
- This indicate that the expiratory time is only one second (i.e. wrong maneuver);however the value indicate normal test.

Lung condition	FEV_1	FVC	FEV_1/FVC
Normal lung	Normal	Normal	Normal
Obstructive disease	Low	Normal	Low
Restrictive disease	Low	Low	Normal or increase
Obstructive+ restrictive	Low	Low	Low

Volumes& capacities not measured by the spirometery:

I. **Residual volume (RV):-** volume of air that is remaining in the lungs after maximum expiration. Its equal (1.2L) in adult male& (1.1L) in adult female.

✓ Higher volumes are found in obstructive lung diseases (due to difficulty in expiration) & lower in restrictive lung diseases.

✓ **The residual volume has the following functions:-**

- Allow easy expansion of the lungs.
- Allow continuous gas exchange throughout the respiratory cycle.
- Prevent complete lungs collapse.

II. Functional residual capacity (FRC):- volume of air that is remaining in the lungs following tidal expiration =ERV +RV.

III. Total lung capacity (TLC):- volume of air accommodated by the lungs at the end of maximum inspiration.it equal (IRV+ TV +ERV+ RV) or (IC+ FRC) or (VC+ RV) = (6L) in adult male& (5L) in adult female.

✓ **RV& FRC are higher in:-**

- Males compared to females.
- Adults compared to children.
- Obstructive lung disease (asthma, chronic bronchitis,& emphysema) compared to lung disease (lung fibrosis).

- The above volumes& capacities can be measured by following methods; **helium dilution** Plethysmography technique or **nitrogen washout technique**.

❖ **Pulmonary ventilation or (Respiratory minute volume)**

- The volume of air inspired or expired per minute
- It equal TV× RR (tidal volume× respiratory rate) =500×12= (6L/min) at rest.

❖ **Alveolar ventilation:-**

- The volume of air that ventilate the alveoli per minute
- = (TV_ Dead space volume)× RR
- = (500_150) × 12= (4200ml/min) or (4.2L/min) at rest.

❖ **Dead space volume (DS)**

- Defined as the volume of air that doesn't participate in gas exchange.
- **It include two types:-**

1) **Anatomical DS:** volume of air that occupies conducting zone.
2) **Physiological DS**: volume of air that occupies the conducting zone (Anatomical DS) plus volume of air in respiratory zone but not participate in gas exchange (eg. air within the upper alveoli that receive low blood supply because of gravity).

- The anatomical DS is about (150mL) in average adult male or (roughly it equals the weight of body in pounds).
- The physiological DS volume= anatomical DS volume+ any additional alveolar air not participate in gas exchange.
- Normally, physiological DS almost equal anatomical DS. The deference being less than (5mL) of air.
- **The anatomical DS volume can be measured by single breath nitrogen test.**

- The physiological DS volume can be measured by **Bohr equation**.

$VO/VT = (PACO_2 - PECO_2)/ PACO_2$

- Note:- VO→ volume of dead space.
- VT→ tidal volume.
- $PACO_2$→ partial pressure of CO_2 in alveolar air.
- $PECO_2$→ partial pressure of CO_2 in expired air.

- Normally $PACO_2$ is the same as $PaCO_2$ (partial pressure of CO_2 in arterial blood). Therefore measurement requires an arterial blood sample to measure CO_2 in blood arteries& a gas analyzer to measure CO_2 in expired air.

- Notice the CO_2 expired from alveoli that contain DS air is zero similar (to the atmosphere) because there is no gas exchange.

To be continued……