41. How does asthma occur?

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42. What are the main causes of asthma?

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43. What is breathing cycle.

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44. Name 4 lung volumes

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45. Name 4 lung capacities

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46. What is the air capacity to prevent collapse of alveoli

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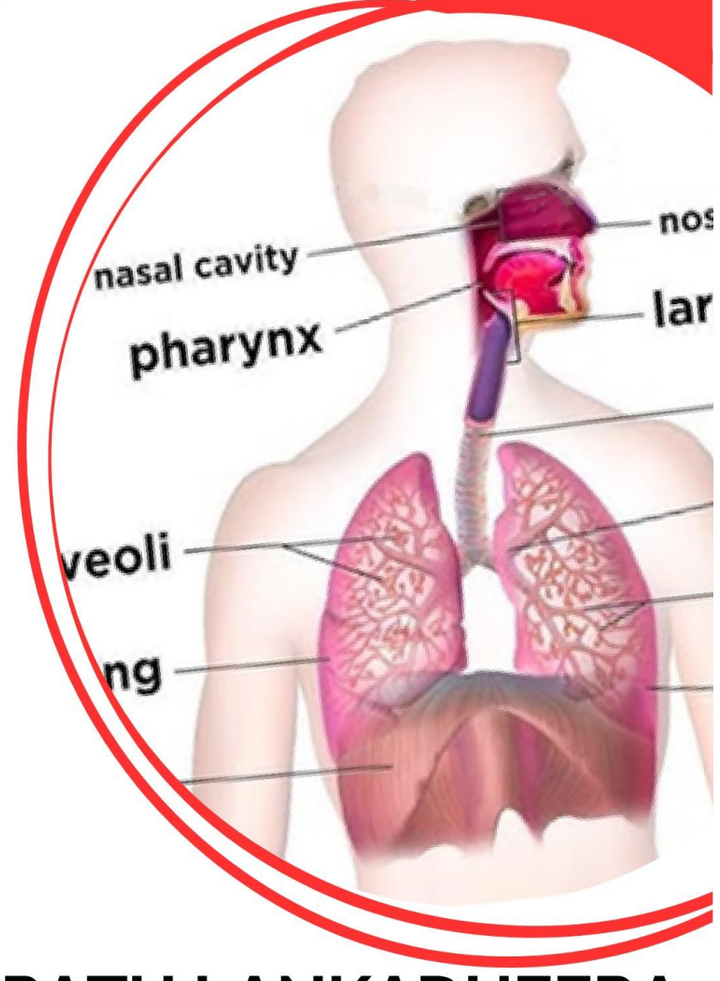
47. What is meant by anatomical death space

……

2025 Revision

Biology
Gas Exchange
Unit 05



Gas exchange in animals

Need of respiratory structures in animals and evolution of complexity of respiratory structures in different animal groups

Respiratory gas exchange (uptake of oxygen into the body and release of carbon dioxide into the external environment) occurs by diffusion. In simple animals e.g. cnidarians and flat worms every cell in the body is close enough to the external environment so that gas exchange can occur directly between all cells and the environment. Diffusion through body surface is adequate as these animals have a simple body form and low energy requirement.

In large animals, body complexity and energy requirement is high and the bulk of the cells in the body lack immediate access to the external environment. Hence, gas exchange through the body surface is not adequate to full fill their energy requirements. As a result, specialized surfaces referred to as respiratory surfaces have evolved where gaseous exchange occurs.

With the increase of the body size and complexity the surface area to volume ratio (A/V) of animals decreases. However, a large surface area is required for efficient gas exchange and thus diverse respiratory structures with large surface area with folding and branching has evolved for efficient gas exchange. Examples for such respiratory structure are Gills, Trachea, and lungs. External projections of the body such as gills were evolved in aquatic animals for efficient extraction of dissolved oxygen from water. On the other hand, surface invaginations like trachea and lungs were evolved in terrestrial animals for efficient extraction of oxygen from the atmosphere.

Characteristics of respiratory surfaces

An effective respiratory surface must have the following properties.

- It must be permeable, and wet so that gases can pass through by dissolving.
- It must be thin because diffusion is only efficient over short distances.
- It should possess a large surface area to allow a sufficient volume of gases to be exchanged according to the organism's need.
- It should possess a good blood supply (maintain a steep diffusion gradient)

Respiratory structures in animals

- Body surface: Cnidarians, Flatworms, Earthworms
- Gills
  - External Gills: marine annelids
  - Internal Gills: Fish, shrimps, prawns

33. What are the effects of cigarette smoking on the respiratory system?

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    .....
    .....

34. Silicosis is another disorder related to the respiratory system. What industries are more at risk for this?

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    .....

35. Explain the condition that occurs when silica particles are inhaled.

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    .....

36. Name another industry-related disease that causes skin tissue destruction and puerperal dystrophy.

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37. What causes about 90% of lung cancer cases?

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38. What is the causative agent of tuberculosis?

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39. What is the most common form of tuberculosis?

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40. What are the symptoms of tuberculosis?

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    .....

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25. Describe what is external respiration and internal respiration.

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26. How many O2 molecules are associated with a hemoglobin molecule?

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27. Is breathing voluntary or involuntary process?

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28. What is the main center of breathing regulation?

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29. Explain the negative feedback mechanism of respiration.

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30. Explain how homeostatic control of breathing takes place depending on pH.

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31. Describe the effect of O2 on breathing regulation center

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32. In addition to the medulla oblongata, where are the additional respiratory control centers located?

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Human Respiratory System

Gross structure and function of the human respiratory system

Human respiratory system consists of the following major parts: nostrils, nasal cavity, pharynx, larynx, a series of branching ducts starting from the trachea, two bronchi one leading to each lung and smaller bronchioles, which finally end in air sacs called alveoli. The bronchioles and the alveoli are contained within the paired, cone-shaped lungs located in the thoracic cavity. The two lungs differ slightly in shape and size. The left lung is slightly smaller than the right because the apex of the heart is slightly to the left of the median plane and it has 2 lobes while the right lung has 3 lobes. Each lung is surrounded by two membranes. The inner membrane, called the visceral pleura adheres to the outer surface of the lungs while the outer membrane called the parietal pleura adheres to the wall of the thoracic cavity. Between these two membranes there is a thin, fluid filled space.

During breathing, air enters the respiratory system through the nostrils. In the nasal cavity air is filtered by hairs and is warmed and humidified as it travels through spaces in the nasal cavity. The nasal cavity leads to the pharynx which is a common passage for both air and food. That means air passage and food passage cross each other. During swallowing of food the larynx moves upwards which allows the epiglottis to close the opening of the larynx called the glottis. This allows food to go down the esophagus to the stomach. The rest of the time the glottis is open so that air can move from the pharynx through the larynx to the trachea. In the larynx are vocal cords which are made up of largely elastic bands of muscles. These vocal cords help produce sound when expired air rushes across the stretched or tensed vocal cords, causing them to vibrate. Both the walls of the larynx and trachea are strengthened by cartilage that help these airways to keep open. The air passes from the trachea into the two bronchi that lead into each lung. Within the lungs the air passes through smaller and smaller branches of the bronchi called bronchioles.

The epithelium found in the major branches of this respiratory tract has cilia and a thin film of mucus. The mucus helps trap the dust and other particulate contaminants in the inhaled air. Then the beating of cilia moves this mucus upwards towards the pharynx where it is swallowed into the esophagus. This process is referred to as the "mucus escalator". It helps clean the respiratory system.

At the tips of tiniest bronchioles are large number of small air sacs clustered together. The air passes into these air sacs called alveoli where gas exchange occurs. The walls of the alveoli are made up of a single layer of flattened epithelial cells that lack cilia. This inner lining of the alveoli is coated by a thin film of fluid. The lungs contain millions of alveoli. This allows a large surface area for gas exchange. Each alveolus is also surrounded by a network of capillaries. Oxygen in the air that enters the alveoli dissolves in the moist film and rapidly diffuse across the thin epithelium into the capillaries. Meanwhile a net diffusion of carbon dioxide occurs from the capillaries into the alveoli. Since there are no cilia in the alveoli, there are white blood cells in the alveoli to engulf foreign particles. Alveoli are also coated with a surfactant that reduces the surface tension thereby preventing the collapse of alveoli due to high surface tension.

16. What is the mechanism of aeration?

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18. Why is human respiration called negative pressure respiration?

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19. Is respiration an active process or a passive process?

    ……

20. Explain the process of respiration.

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    ……...

21. Is normal expiration active or passive?

    ……..

22. Explain the process of respiration.

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    ……...

23. Which muscles contribute to gaining additional volume depending on the level of activity?

    ……..

24. Why is lungs are an efficient respiratory surface?

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8. What is the significance of the fact that the walls of the larynx and trachea are reinforced by cartilage?

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9. What is mucus escalation?

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10. What is the important function of the surfactant covering the cavity?

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11. Why is human respiration called negative pressure respiration?

……

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12. Which additional muscles contribute to respiration depending on the level of activity in humans?

……..

13. What muscles are involved in normal breathing?

……...

14. Write the reaction that shows the reversible interaction of hemoglobin molecule with oxygen.

……..

15. What is the total lung capacity?

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Mechanism of ventilation of the lungs

Ventilation of the lungs is necessary to maintain high oxygen and low carbon dioxide concentrations in the alveoli or the gas exchange surface.

- Ventilation is accomplished by breathing, which is the alternating movement of air into (inhalation) and out of (exhalation) the lungs.
- Humans employ what is referred to as negative pressure breathing where air is pulled rather than pushed into lungs.
- Inhalation is an active process. Contraction of rib muscles or intercoastal muscles and the diaphragm which is a sheet of skeletal muscle that forms the bottom of the thoracic cavity leads to the expansion of the thoracic cavity. Thereby, increasing its volume.
- The visceral and parietal pleurae surrounding the lung stick together due to the surface tension of the fluid between these two membranes. This allows the two membranes to slide smoothly pass each other. Hence, as the volume of the thoracic cavity increases, the lung volume increases as well.
- As a result, the pressure within the lungs decrease relative to the outside air.
- This creates a pressure gradient between the atmosphere and the lungs.
- Thus, air flows from a high pressure in the atmosphere to a lower pressure in the lungs.This is inhalation.
- During exhalations which is usually a passive process, the rib muscles and the diaphragm relax. This cause the volume of the thoracic cavity to reduce.
- As a result, the pressure inside the lungs increase in relation to the air outside. This pressure forces air to move out of the lungs through the respiratory tubes into the atmosphere. This is exhalation.

When a man is at rest contraction of rib muscles and contraction of diaphragm are enough for breathing. However, depending on the activity level, additional muscles may be used to aid deep breathing such as muscles of the neck, back and chest. In deep inspiration, these muscles further help to increase the volume of the thoracic cavity by raising the rib cage. e.g. during exercise

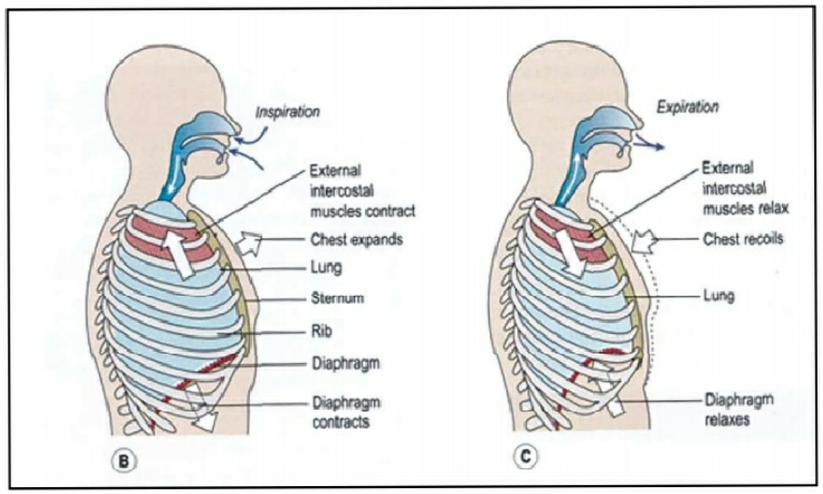

Fig 5.25: (A) and (B) Changes in chest volume during inspiration and expiration

- The lungs serve as an efficient respiratory surface because: Alveoli create a large surface area for gas exchange.
- Alveoli and capillary walls are both lined by simple squamous epithelia which reduce the distance the gasses need to travel by diffusion.
- The alveoli surface is moist to dissolve respiratory gasses for diffusion.
- Alveoli are highly vascularized which enables the maintenance of a steep diffusion gradient of respiratory gasses

Exchange of gasses between air and blood; blood and tissues

Gas exchange at the alveoli and in the tissues is a continuous process. It requires transport of O_2 from the lungs to the blood and movement of CO_2 from the blood (referred to as external respiration) and movement of O_2 from blood to the tissues and CO_2 from tissues to the blood (referred to as internal respiration).

Diffusion of O_2 and CO_2 requires partial pressure gradients between the alveolar air in the lungs and blood (during external respiration) and blood and tissues (during internal respiration).

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9. Name the animals given below that have respiratory structures

Body surface - …….

External gills - …….

Internal Gills - …….

Tracheal System - …….

Lungs - …….

Skin - …….

Book lungs - …….

5.3.5 - Structure and function of the human respiratory system

1. What is the normal pH of human blood?

……

2. Draw a flow diagram to show the path of inhaled air from the nostrils to the trachea.

……

……

3. What structures located in the lungs important for respiration ?

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4. Why is the left lung smaller than the right lung?

……...

5. Indicate the number of lobes in each lung.

……..

6. What are the two membranes surrounding a lung?

……...

7. When breathing in, the air entering the nasal cavity undergoes 3 main changes. What are they?

Gaseous exchange in animals

1. What is the mode of passive transport by which respiratory gases are exchanged in animals?

   ……...

2. Which simple animals have each body cell in close enough contact with the external environment?

   …….. …….

3. Why is gas exchange through body surfaces by simple diffusion sufficient for those animals?

   ……...

4. Why do large-bodied animals fail to perform gas exchange efficiently

   ……

   …….

5. What happens to surface/volume ratio for animal with greatest body size and complexity?

   ……..

6. How have respiratory surfaces evolved to provide a large surface area effect for efficient gas exchange?

   ……...

7. What respiratory surfaces have evolved to efficiently obtain O2 in water and air?

   …….

   …….

Characteristic features of respiratory surfaces

8. Mention the characteristics of the respiratory surfaces and state the reasons.

   ……

   …….

During inhalation, fresh air mixes with the stale air in the lungs. This mixture in the lungs has a higher partial pressure of oxygen (PO_2) and a lower partial pressure of carbon dioxide (PCO_2) than the blood in the alveolar capillaries. There is thus a concentration gradient favoring the diffusion of these two gases in opposite directions. Net diffusion of O_2 takes place from the air in the alveoli to the blood and net diffusion of CO_2 takes place from the blood into the alveoli.

When O_2 molecules diffuses into blood capillaries they bind to heamoglobin in the red blood cells. Four molecules of O_2 bind reversibly with one molecule of haemoglobin and form oxyhaemoglobin.

$$Hb + 4\,O_2 \rightleftharpoons HbO_8$$

When blood leaves the alveolar capillaries the oxygen and carbon dioxide partial pressures are in equilibrium with those of alveoli air. Once this blood returns to the heart through pulmonary veins, it is pumped through the systemic circuit.

Blood reaching the tissues in the systemic capillaries have a higher PO_2 and a lower PCO_2 than in the tissues. These partial pressure gradients result in the net diffusion of O_2 from the blood stream into the tissue and CO_2 diffusion from the cells into the blood stream across the extracellular fluid/interstitial fluid. This is called unloading of O_2 and loading of CO_2. Then the blood returns to heart and pumped to lungs again.

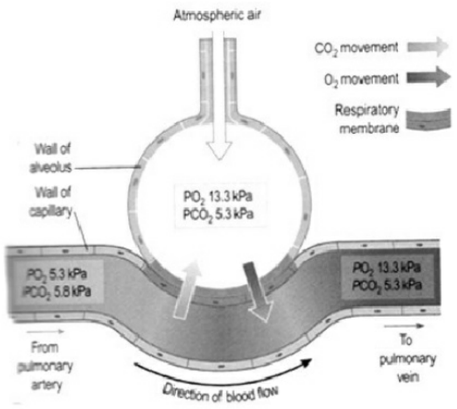


Fig 5.26: External respiration

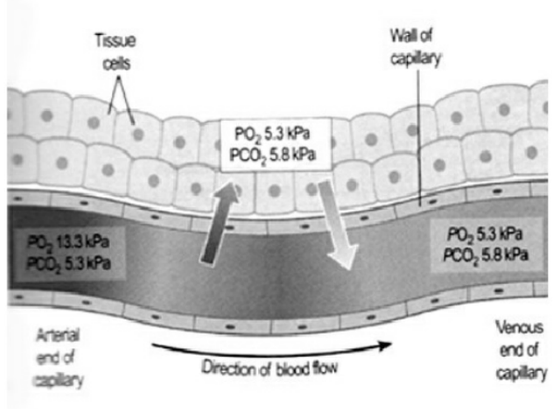


Fig 5.27:Internal respiration

(Memorization of values are not expected)

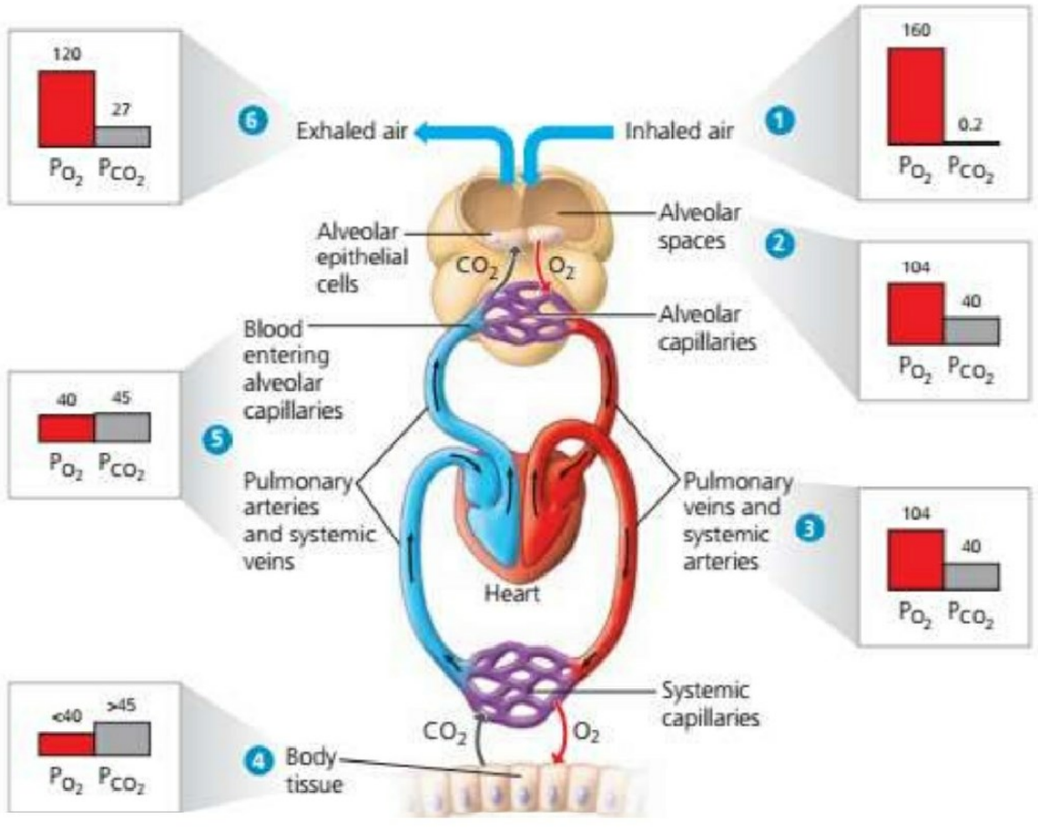


Fig 5.28: Loading and unloading of respiratory gases

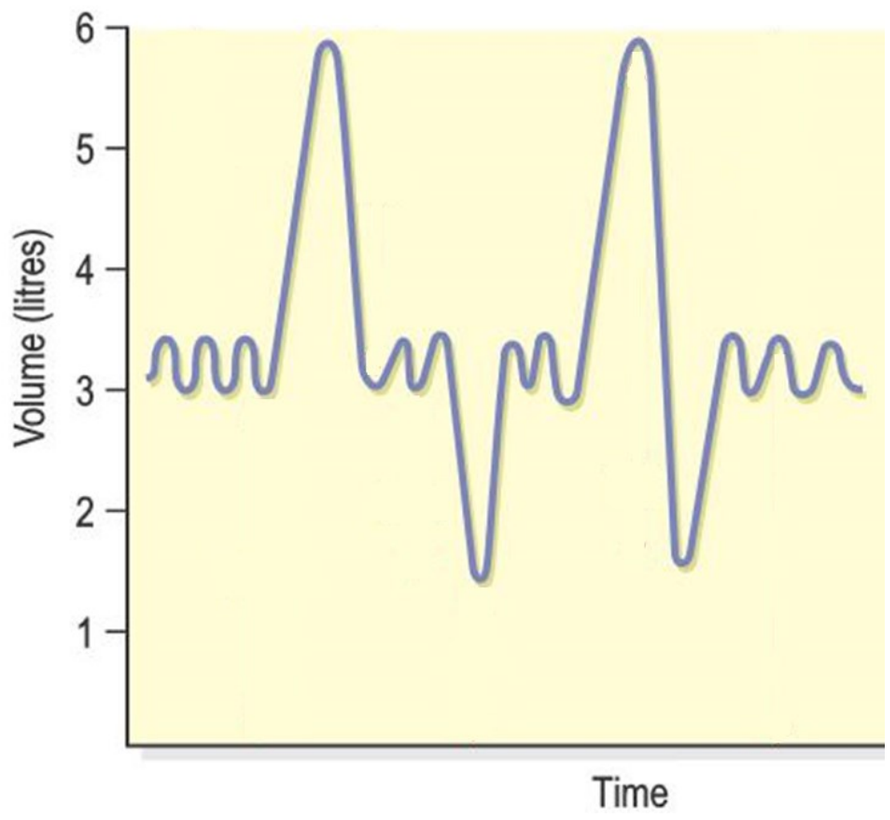
(Memorization of values are not expected)

Homeostatic control of Breathing

- Typically breathing is regulated by involuntary mechanisms. These involuntary mechanisms help coordinate gas exchange with blood circulation and metabolic demands
- Medulla oblongata is the main breathing regulating center found at the base brain. There are a pair of breathing control centers found in medulla oblongata and they are responsible for regulating the breathing rhythm.
- A negative-feedback mechanism is involved in regulating this process. Sensors which detect stretching of the lung tissues are found in the lungs. During inhalation, these sensors send nerve impulses to the neurons that act as control circuits in the medulla oblongata and further inhalation is inhibited and this prevents the lungs from over expanding.
- To regulate breathing, the medulla oblongata depends on pH changes in tissue fluids. The pH of tissue fluid is an indicator of blood carbon dioxide concentration. For example, when metabolic activities increase, the concentration of CO_2 in the

- **Total lung capacity (TLC):** The maximum volume of air the lungs can hold or the sum of all lung volumes. This is normally around 6000 mL.

In addition, some of the inspired air fills the system of branching conducting tubes (trachea, bronchi and bronchioles) and never contributes to the gas exchange in the alveoli. This volume of air is referred to as the anatomical dead space and it is typically about 150 mL.



Asthma

Asthma is characterized by wheezing and chest tightness causing breathing difficulty. This is caused by the sudden contractions of smooth muscles in the walls of the bronchioles which causes the bronchioles to narrow or even close. During this time breathing causes whistling or wheezing sound. The cause of asthma is an over reaction of an immune response to stimuli like pollen, dust, mites, spores, particular food, cold air, exercise, smoking gases. Anti-inflammatory drugs help control.

Respiratory cycle and lung volumes and capacities

Inhalation and exhalation during a single breath is referred to as a respiratory cycle. The amount of air that flows in and out of the lungs depends on the conditions of inspiration and expiration. Thus, four respiratory volumes are described.

- **Tidal volume (TV)**: This is the volume of air passing into and out of the lung with each breath during normal breathing. On average it is about 500 ml in a resting adult human.
- **Inspiratory reserve volume (IRV):** This is the extra volume of air that can be forcibly inhaled beyond the tidal volume.
- **Expiratory reserve volume (ERV):** The extra volume of air which can be forcibly expelled from the lungs after a normal expiration.
- **Residual volume (RV):** The volume of air that remains in the lungs even after forceful expiration. This is on average is about 1,200 ml.

Specific combinations of respiratory volumes are called respiratory (lung) capacities. Thus, respiratory capacities always consist of two or more lung volumes. The respiratory capacities are important to determine the respiratory status of a person.

- **Inspiratory capacity (IC):** The total volume of air that can be inspired with maximum effort

Thus, IC = TV + IRV

- **Functional residual capacity (FRC):** The volume of air remaining in the lungs at the end of a normal expiration.

  Thus, FRC = RV + ERV

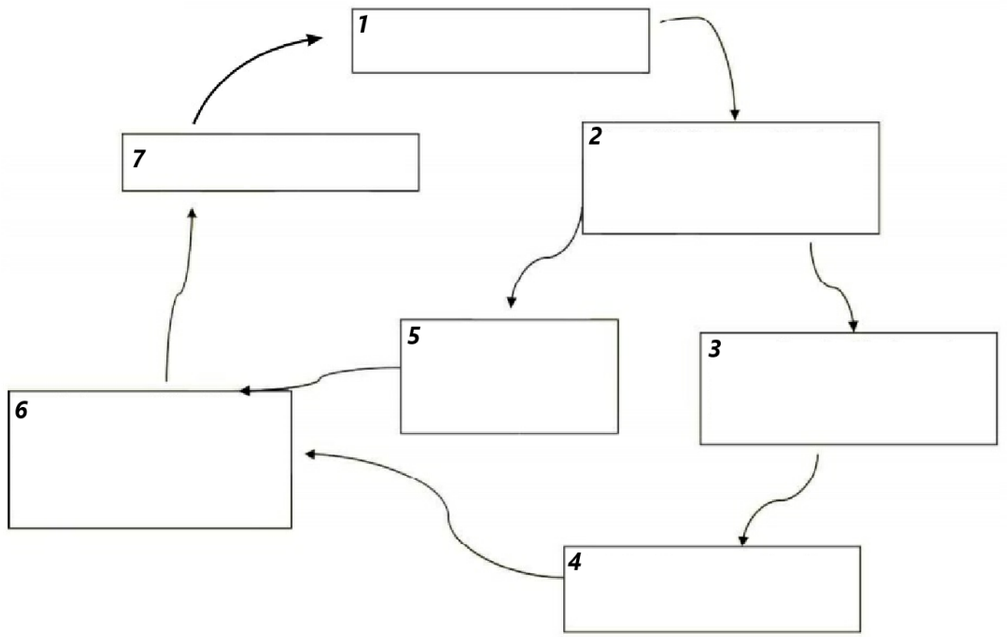
- The functional residual capacity is important for continuous exchange of gas in the alveoli and to prevent the collapse of the alveoli during expiration.
- **Vital capacity (VC):** The maximum volume of air which can be inhaled and exhaled. It is normally around 3100 mL in women and 4800 mL in men.

  VC = TV + IRV + ERV

blood increases. Because CO_2 diffuse into the cerebrospinal fluid, this results in an increase of CO_2 concentration in the cerebrospinal fluid as well. There CO_2 reacts with water and form carbonic acid (H_2CO_3). H_2CO_3 dissociate into HCO_3^- and H^+

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

- Hence, a high CO_2 concentration results in an increase in H+ concentration, thereby a lower pH.
- This pH change is detected by the sensors in the medulla oblongata and in major blood vessels (carotid arteries and aorta).
- Sensors in the medulla and major blood vessels detect this decrease in pH. In response, the control circuits in medulla increase the depth and rate of breathing until the excess CO_2 is removed in exhaled air and the pH of blood comes to its normal value which is 7.4
- The O_2 level has little influences on the breathing control centers. But, when O_2 concentration becomes very low, O_2 sensors found in the aorta and the carotid arteries send impulses to the medulla oblongata to increase the breathing rate.
- The regulation of breathing is also modulated by additional neural circuits in the pons varolii, a part of the brain stem found above the medulla.



Disorders of the respiratory system

The effect of smoking on the smooth functioning of the respiratory system

- Cigarette smoke harms nearly every organ in the body including the organs of the respiratory system and increase the risk of illness, disability and death. Smokers inhale large number of chemicals which mainly come from burning tobacco. Some of these inhaled compounds are chemically active and can trigger damaging changes in the body.
- Nicotine is among the compounds inhaled in tobacco smoke which is the addictive drug in the smoke. It temporarily increases the rate of heart beat and constriction of peripheral blood vessels causing a temporary increase in blood pressure.
- Cigarette smoke stimulates the secretion of mucus by the goblet cells and inhibits the action of cilia in the respiratory tract causing accumulation of mucus in bronchioles and blocking them, leading to bronchial inflammation or bronchitis. As a result, breathing may become difficult.
- Some chemicals such as hydrogen cyanide in cigarette smoke stops the cilia from working properly. Due to loss of action of cilia, dust and other particulate matter get collected in the lung, resulting in an increase in phagocytic cells in the lung tissue. Due to release of large amounts of lytic enzymes by these cells, the alveolar tissue is destroyed thus reducing the effective area available for gas exchange.
- Carbon monoxide (CO) present in tobacco smoke is absorbed into the blood and is able to bind to hemoglobin better than oxygen and combines irreversibly with hemoglobin. Thus it decreases the amount of oxyhaemoglobin produced. Therefore, oxygen transport through blood is decreased.
- Tobacco smoke also contains a large number of cancer-causing substances (carcinogens). Nearly 90% of lung cancers are due to smoking. Long term exposure to such chemicals in cigarette smoke results in the proliferation of cells in the bronchial epithelium, forming a mass of abnormal cells. A cancer may develop among these cells. If these cells break free, the cancer may spread to other parts of the lungs and or to other organs.
- Passive or second hand smoking will also result in the above mentioned ill effects.

Silicosis

This may be caused by long-term exposure to dust containing silica compounds. High risk industries are,

- Quarrying granite, slate, sandstone
- Mining hard coal, gold, tin, copper
- Stone masonry and sand blasting
- Glass and pottery work

When silica particles are inhaled they accumulate in the alveoli. These particles are ingested by macrophages, some of which remain in the alveoli and come out in to the connective tissue around bronchioles and blood vessels close to the pleura. Progressive fibrosis is stimulated which eventually obliterates the blood vessels and respiratory bronchioles. Gradual destruction of lung tissue eventually leads to pulmonary hypertension and heart failure.

Asbestos related diseases - Asbestosis

Those who are involved in making or using products containing asbestos are at risk. This occurs when asbestos fibers are inhaled with dust. In spite of their large size the particles penetrate the level of respiratory bronchioles and alveoli. Macrophages accumulate in the alveoli and the shorter asbestos fibers are ingested. The larger fibers are surrounded by macrophages, protein materials and iron deposits. The macrophages that have engulfed fibers move out of the alveoli and accumulate around respiratory bronchioles and blood vessels, stimulating the formation of fibrous tissue. These cause progressive destruction of lung tissue and pulmonary hypertension.

Lung cancer

Nearly 90% of lung cancer is due to smoking. When one smokes, the nasal hairs, mucus and cilia in the respiratory tract that otherwise is sufficient to protect the lung from chemical and biological irritants, are overwhelmed and eventually stop functioning. As a result, irritants, free radicals, carcinogens and pathogens accumulate in the lungs. Eventually these cause lung cancer.

Tuberculosis (TB)

Tuberculosis is an infectious disease caused by the bacterium *Mycobacterium tuberculosis.* The bacterium spreads when an infected person coughs and the bacterium enters the body of an uninfected person through inhaled air. The most common form is Pulmonary TB which affects the lungs. Other organs may also be affected. Transmission of pulmonary TB is by inhaling the bacterium into the lungs. This bacterium can survive in the air and in the house dust for long periods. Malnutrition and other infectious can reduce resistance to the disease.

Symptoms of this disease are loss of appetite, loss of weight, excessive sweating, fever, a racking cough and spitting up blood.