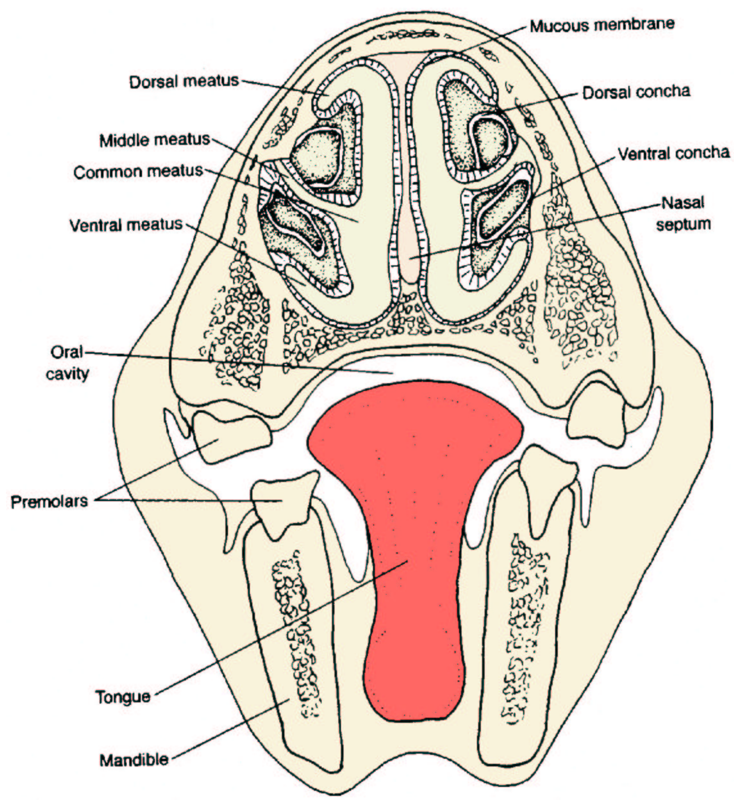
Respiratory System
ANS 215
Physiology and Anatomy of
Domesticated Animals

I. Structure and Function of the Respiratory System

A. Respiration – means by which animals obtain and use oxygen and eliminate carbon dioxide

B. Respiratory apparatus

1. Lungs and air passages leading to them
   a. nostrils
      i. external openings for the paired nasal cavities
      ii. nostril dilation is advantageous when more air is required
   b. nasal cavities
      i. nasal cavities separated from each other by nasal septum and from the mouth by the hard and soft palates
      ii. Each nasal cavity contains mucosa-covered turbinate bones (conchae) that project to the interior, for the dorsal and lateral walls separating the cavity into passages known as the common, dorsal, middle, and ventral meatuses.



Transverse section of the horse head showing the division of the nasal cavities. The airways are noted as the dorsal, middle, ventral, and meatuses. The conchae consist of turbinate bones covered by a highly vascularized mucous membrane. Incoming air is exposed to large surface area for adjustment of its temperature and humidity.

      iii. The mucosa of the turbinates is well vascularized and serves to warm and humidify inhaled air.

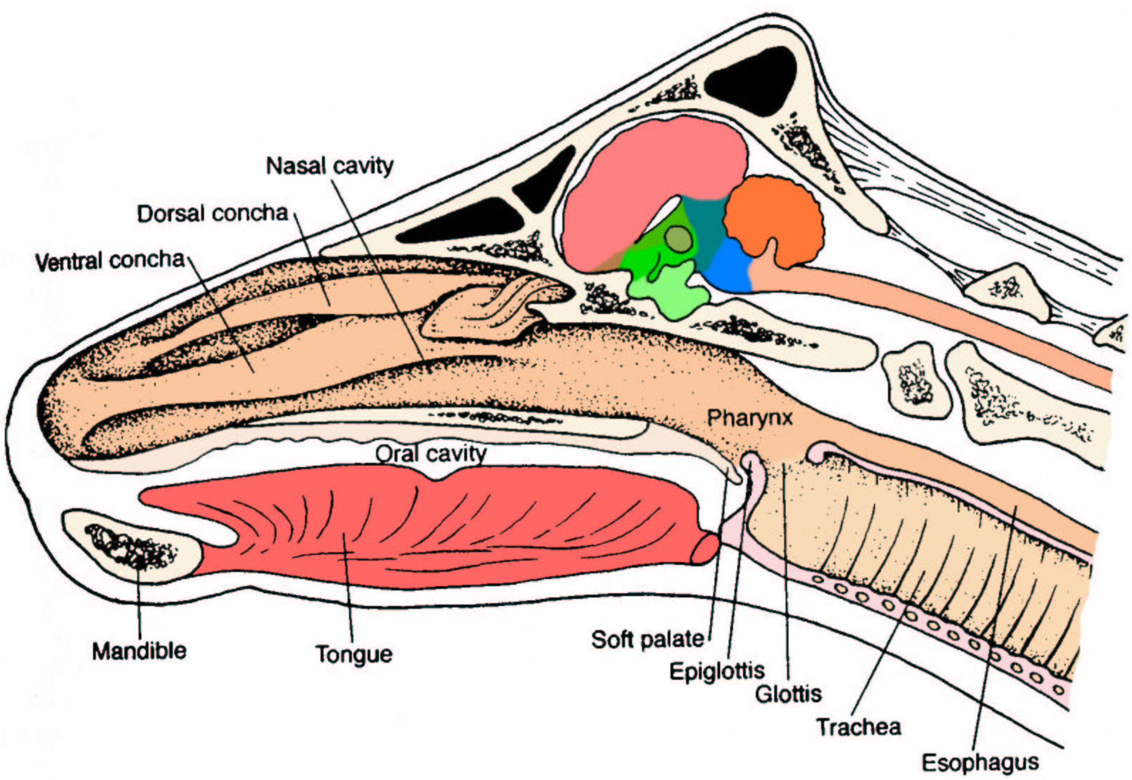
iv. Another function for the conchae involves cooling blood through a counter-current heat exchange mechanism. Arteries that supply blood to the brain divide into smaller arteries at the base of the brain. These are bathed in a pool of venous blood that comes from the walls of the nasal cavities where it has been cooled. This keeps brain temperature 2 – 3 degrees cooler.

c. pharynx

i. caudal to the nasal cavities and is a common passageway for air and food. The openings to the pharynx include two posterior nares, two eustachian tubes, a mouth (oral cavity), a glottis, and an esophagus

ii. The opening from the pharynx leading to the continuation of the respiratory passageway is the glottis.

iii. Immediately caudal to the glottis is the larynx, origan of phonation (called the sirinx in birds)



Midsagittal section of the head of a cow with nasal septum removed. The stippled area represents the pathway of air through the nasal cavity, pharynx, and trachea. The glottis is the opening to the trachea.

d. trachea

i. Primary passageway for air into the lungs

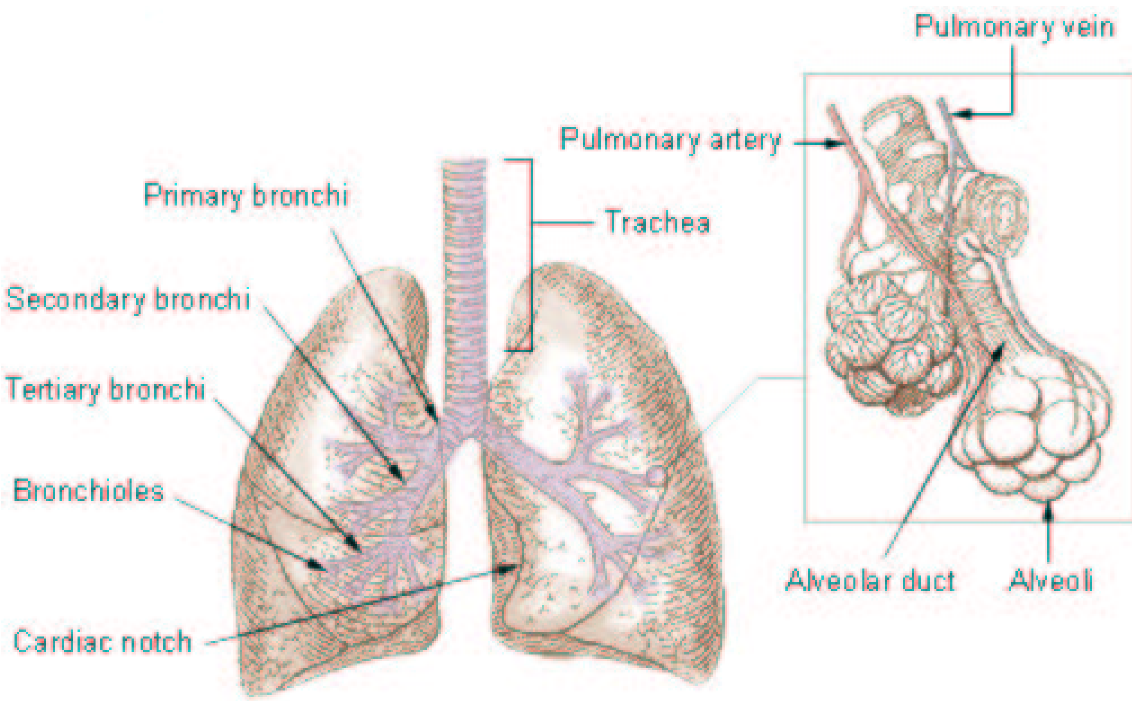
ii. Continued from the larynx cranially and divides caudally to form the left and right bronchi

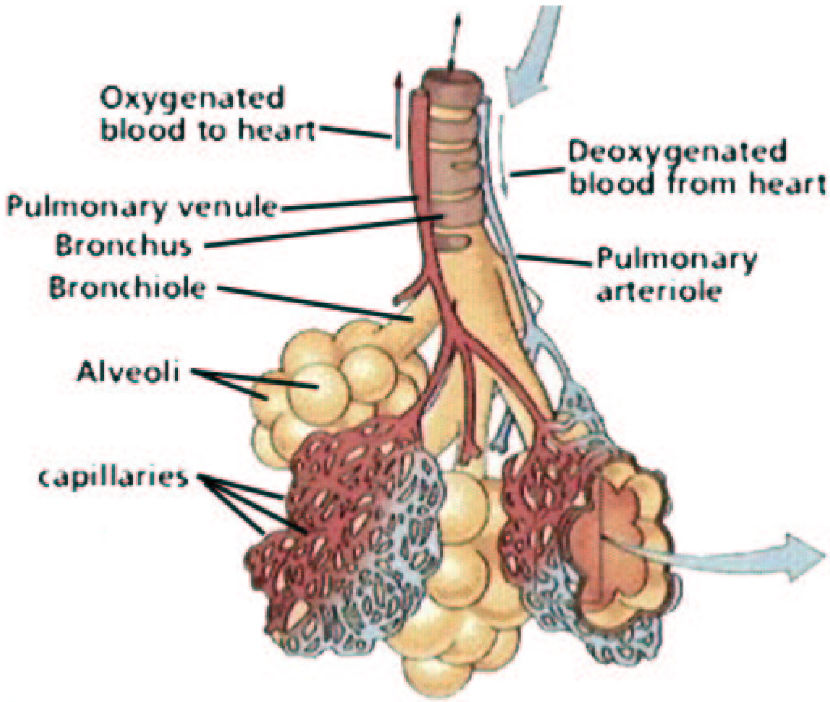
iii. tracheal wall contains cartilaginous rings to prevent collapse of the tracheal airway

iv. Each tracheal ring is incomplete (not joined dorsally), which permits variation in diameter for increased ventilation requirements.

v. Right and left bronchi and their subdivisions continue all the way to the alveoli, the final and smallest subdivisions of the air passages.

vi. subdivision of the trachea to the alveoli are:
- bronchi
- bronchioles
- terminal bronchioles
- respiratory bronchiles
- alveolar duct
- alveolar sac
- alveoli





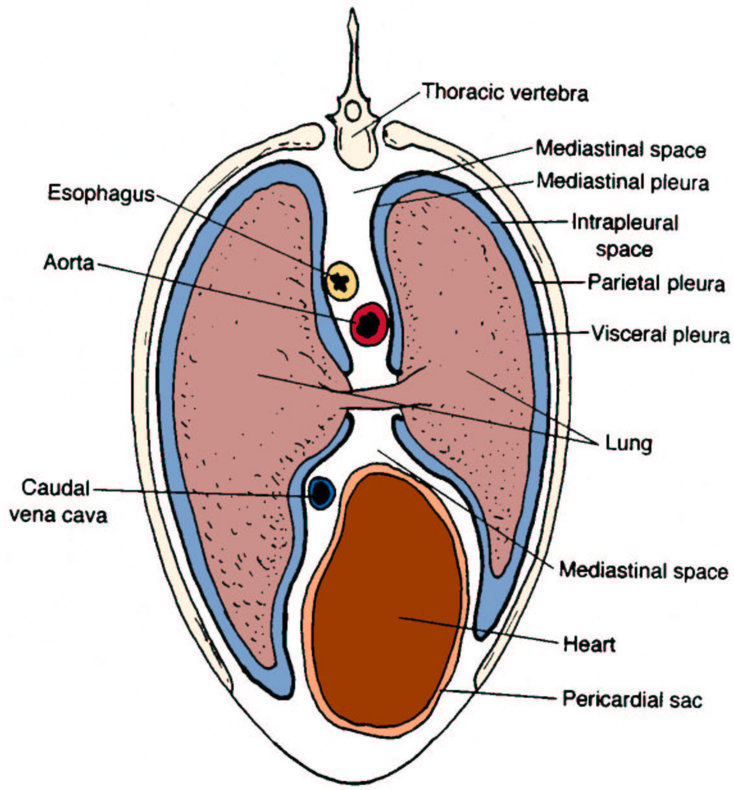
e. pulmonary alveoli
    i. principal sites of gas diffusion between air and blood
    ii. the separation of air and blood, and thus the diffusion distance is minimal at the alveolar level
    iii. venous blood from the pulmonary artery becomes arterial blood and is returned to the left atrium by the pulmonary veins
    iv. The dark purple color of venous blood becomes bright red arterial blood during the resaturation of hemoglobin with new oxygen.
    v. The lungs are the principle structures of the respiratory system. They are paired structures and occupy all space in the thorax that is not otherwise filled. The lungs have an almost friction-free environment within the thorax, because of the pleura, a smooth serous membrane.

f. pleura
    i. consists of a single layer of cells fused to the surface of a connective tissue layer, it envelopes both lungs
    ii. The pleura for the right and left lung meet near the midline, where it reflects upward (dorsally), turns back on the inner thoracic wall, and provides for its lining.
    iii. The space between the respective visceral pleura layers as they ascent to the dorsal wall is known as the mediastinal space.
    iv. Within the mediastinal space are the vena cava, thoracic lymph duct, esophagus, aorta, and trachea.
    v. The mediastinal space is intimately associated with the

intrapleural space.

vi. Pressure changes in the intrapleural space are accompanied by similar changes in the mediastinal space.

vii. Pressure changes in the mediastinal space are accompanied by changes within the mediastinal structures.



Transverse section of equine thorax showing the relationships of the visceral, parietal, and mediastinal pleura. The aorta, esophagus, vena cava , and thoracic lymph duct (not shown) are within the mediastinal space. The esophagus, vena cava, and lymph duct (soft structures) respond by increasing and decreasing pressures within their lumens. They are associated with similar changes in intrapleural and mediastinal spaces.

II. Factors Affecting Respiration and Ventilation

A. Mechanics of respiration

1. Respiratory cycles

a. A respiratory cycle consists of an inspiratory phase, followed by an expiratory phase.

b. Inspiration involves an enlargement of the thorax and lungs.

c. The thorax enlarges by contraction of the diaphragm and contraction of the appropriate intercostal muscles.

i. diaphragmatic contraction enlarges the thorax in a caudal direction

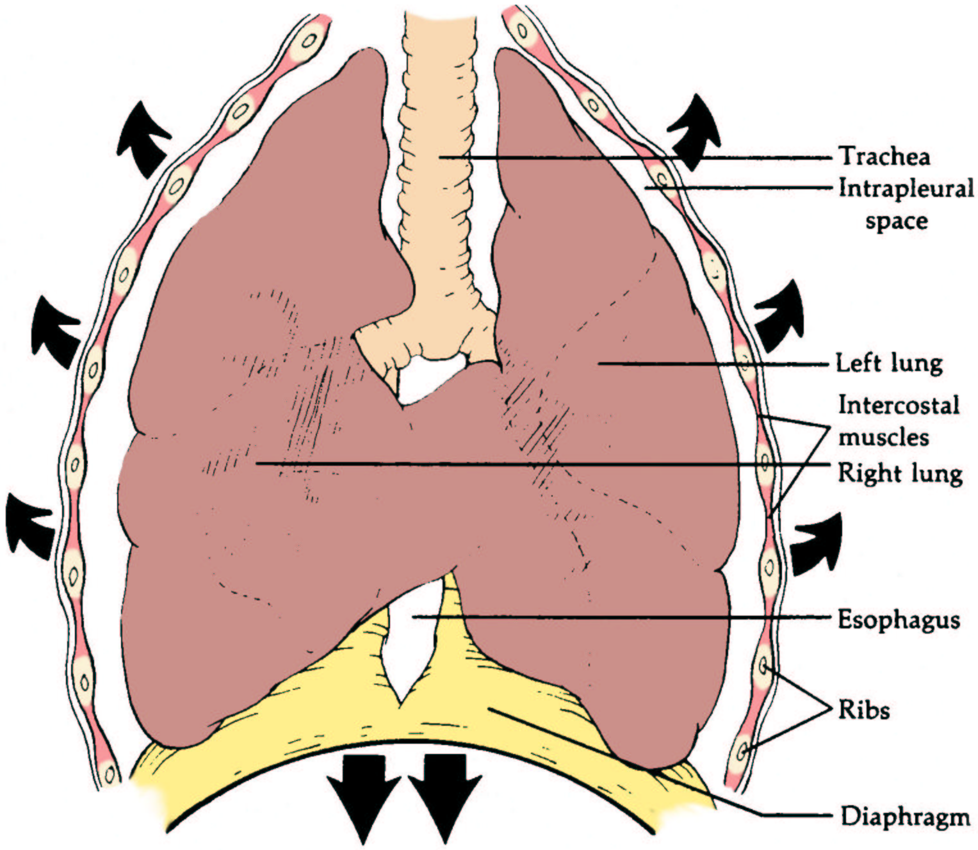
ii. intercostal muscle contraction enlarges the thorax in a cranial and outward direction

d. Under normal breathing conditions, the inspiration of air requires more effort than expiration however, expiration can become

labored during accelerated breathing and also when there are ‘
impediments to the outflow of air.

e. The appropriate intercostal muscles contract to assist in expiration.

f. Other skeletal muscles can aid in either inspiration or expiration, such as the abdominal muscles.

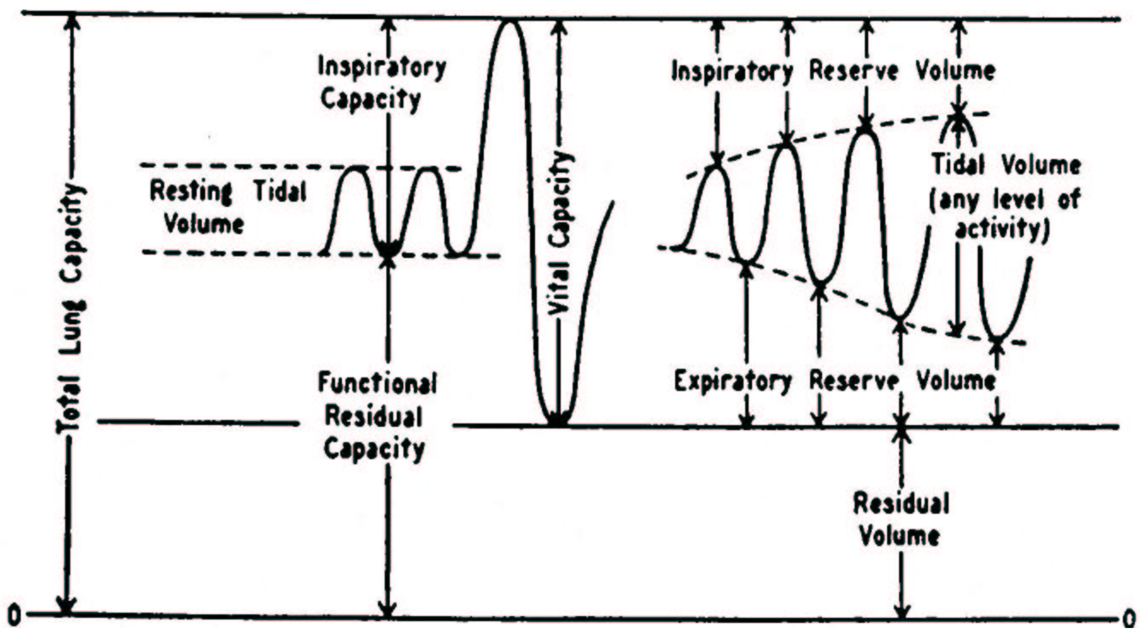


Schematic of the thorax during inspiration (ventral view). Shown are the directions of enlargement (arrows) when the diaphragm and inspiratory intercostal muscles contract during inspiration.

B. Types of breathing
   1. There are two types of breathing.
      a. abdominal
         i. characterized by visible movements of the abdomen
      b. costal
         ii. characterized by pronounced rib movements

C. States of breathing
   1. Variations in breathing are related to the frequency of breathing cycles,

depth of inspiration, or both.
2. dyspnea – difficult breathing
3. hyperpnea – breathing characterized by increased depth, frequency, or both; usually follows physical exertion
4. polypnea – rapid, shallow breathing
5. apnea – absence of breathing



Subdivisions of lung volume.

D. Pulmonary volumes and capacities
1. Conventional descriptions for lung volumes are either associated with the amount of air within them at any one time or the amount associated with a breath.
2. Tidal volume is the amount of air breathed in or out in a respiratory cycle.
3. Inspiratory reserve volume is the amount of air that can still be inspired ‘ after inhaling the tidal volume.
4. Expiratory reserve volume is the amount of air that can still be expired after exhaling the tidal volume.
5. Residual volume is the amount of air remaining in the lungs after the most forceful expiration.
6. Combinations of two or more of the above volumes is refered to as capacities.
7. Total lung capacity is the sum of all volumes.
8. Vital capacity is the sum of all volumes over and above the residual volumes.

9. Functional residual capacity is the sum of the expiratory reserve volume

and the residual volume.

a. this is the lung volume ventilated by the tidal volume
b. serves as reservoir for air and helps to provide for consistency to blood concentrations of respired air

Respiratory Frequency for Several Animal Species Under Different Conditions

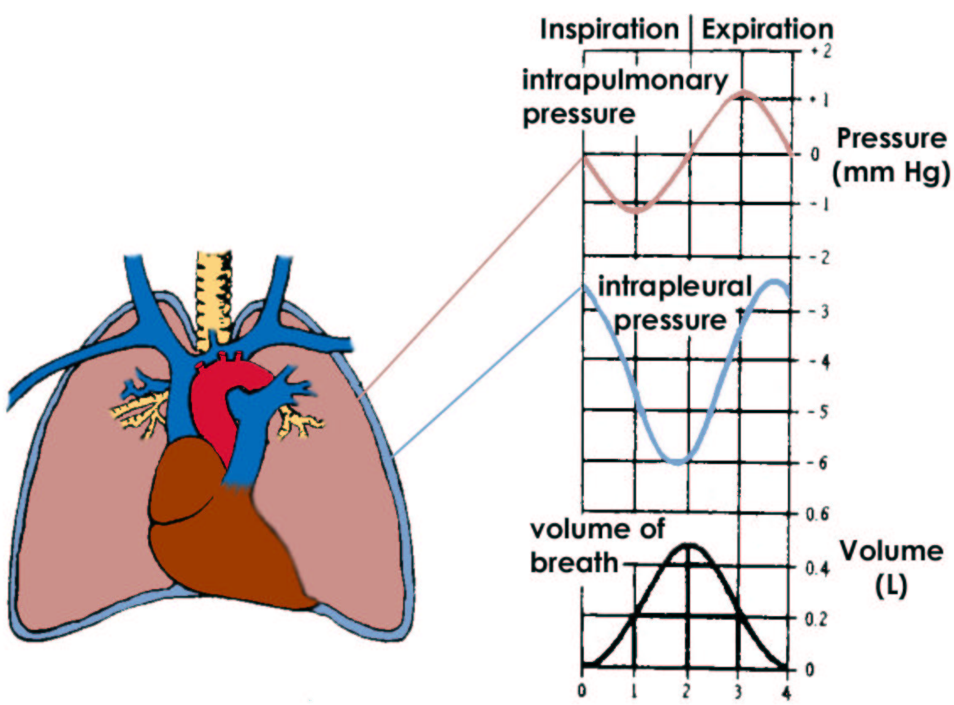
Animal	Number	Condition	Cycles/min. Range	Cycles/min. Mean
Horse	15	Standing (at rest)	10-14	12
Dairy cow	11	Standing (at rest)	26-35	29
	11	Sternal recumbency	24-50	35
Dairy calf	6	Standing (52 kg, 3 weeks old)	18-22	20
	6	Lying down (52 kg, 3 weeks old)	21-25	22
Pig	3	Lying down (23 - 27 kg)	32-58	40
Dog	7	Sleeping (24^oC)	18-25	21
	3	Standing (at rest)	20-34	24
Cat	5	Sleeping	16-25	22
	6	Lying down, awake	20-40	31
Sheep	5	Standing, ruminating, ½” - 1¼" wool, 18^oC	20-34	25
	5	Same sheep and conditions only at 10^oC	16-22	19

E. Respiratory frequency
   1. Refers to the number of respiratory cycles per minute
   2. Excellent indicator of health status
      a. subject to numerous variations
         i. body size
         ii. age
         iii. exertion
         iv. environmental temperature
         v. pregnancy
         vi. degree of filling of digestive tract
         vii. state of health
   3. Usually increases during disease

F. Respiratory pressures
   1. Concentrations of gasses are usually expressed as pressures.
   2. Partial pressure
      a. When considering the equilibrium of two gas mixtures, separated by a permeable membrane, it is necessary to consider each gas in the mixture separately.
      b. defined as the pressure exerted by a particular gas in a mixture of gasses
      c. The sum of the partial pressures is the total gas pressure.
   3. Atmospheric air
      a. The total pressure of 1 atmosphere (atm) is 760mmHg.

b. Composition of atmospheric air:
   i. 21.0% oxygen 159 mmHg
   ii. 0.03% carbon dioxide 0.23mmHg
   iii. 79.0% nitrogen 600mmHg

4. Alveolar air
   a. lower oxygen, higher carbon dioxide and water vapor
5. Pulmonary ventilation
   a. process of exchanging gas in airways and alveoli with atmospheric gas
6. Dead space ventilation
   a. tidal volume ventilates alveoli and airways leading to alveoli
   b. Because there is no diffusion of oxygen and carbon dioxide across membranes of airways, this is referred to as dead space.
   c. The other part of dead space ventilation involves alveoli with diminished capillary perfusion.
   d. therefore tidal volume has a dead space and an alveolar component
   e. Dead space ventilation assists in tempering and humidifying air and in the cooling of the body (e.g. panting).



Intrapleural and intrapulmonic (intrapulmonary) pressures associated with inspiration and expiration.

G. Pressures that accomplish ventilation
1. Intrapulmonic and intrapleural pressures
   a. The pressure within the lungs is referred to as intrapulmonic

pressure.

b. The pressure outside the lungs, but within the pleural cavity is referred to as intrapleural pressure.

c. Air flows into the lungs, because the intrapulmonic pressure drops below the intrapleural pressure.

d. Air flows out of the lungs, because the intrapulmonic pressure exceeds the intrapleural pressure.

e. Intrapulmonic pressure falls when the lungs expand and the recoil tendency of the lungs causes pressure to rise.

f. The total pressure in intrapleural space is in equilibrium with venous blood and is slightly lower than atmospheric pressure.

2. Pneumothorax
   a. If the intrapleural space is opened to the atmosphere it would not be possible for diaphragmatic contraction to generate a greater vacuum than in the intrapleural space.
   b. A respirator is needed to maintain breathing until closure of hole and reinflation of the lungs.
3. Mediastinal pressure
   a. reduced during inspiration when the intrapleural pressure is reduced
   b. allows for expansion of vena cava, thoracic lymph duct, and esophagus

III. Diffusion of Respiratory Gasses

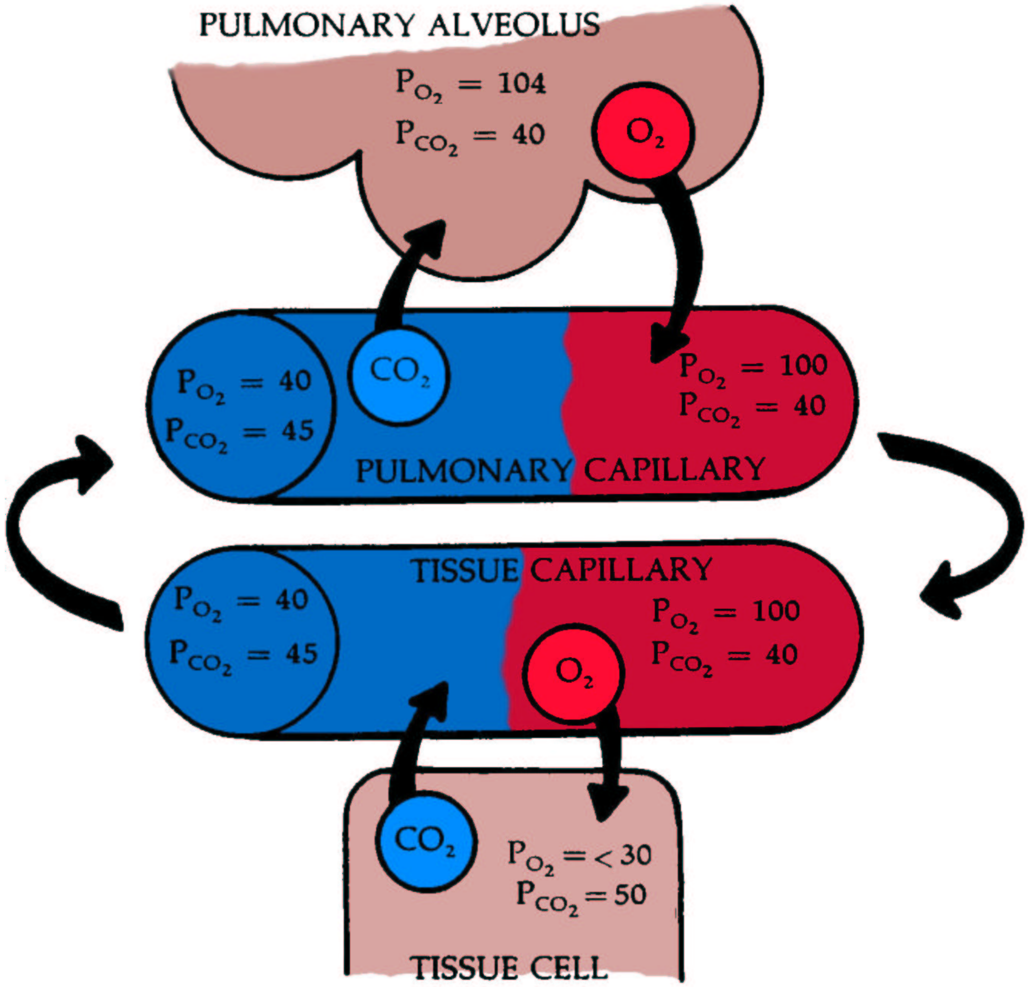
A. Respiratory gasses diffuse readily throughout the body tissues.

B. Because of its lipid solubility, carbon dioxide diffuses about 20 times more readily than oxygen through membranes.

Total & Partial Pressures (mm Hg) of Respiratory Gases in Humans at Rest (sea level)

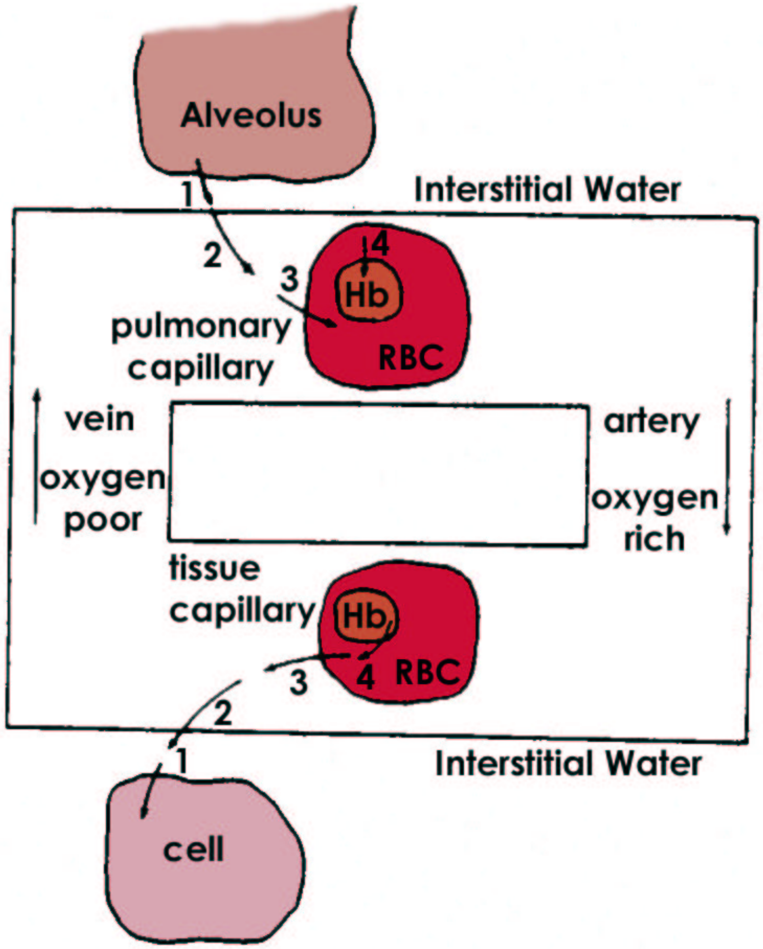
Gases	Venous blood	Alveolar air	Arterial blood	Tissues
Oxygen	40	104	100	30 or less
Carbon dioxide	45	40	40	50 or more
Nitrogen	569	569	569	569
Water vapor	47	47	47	47
Total	701	760	756	696

C. The aqueous environment of the body ensures a constant water vapor pressure and the body does not utilize nitrogen, therefore primary gas pressure changes are in oxygen and carbon dioxide.



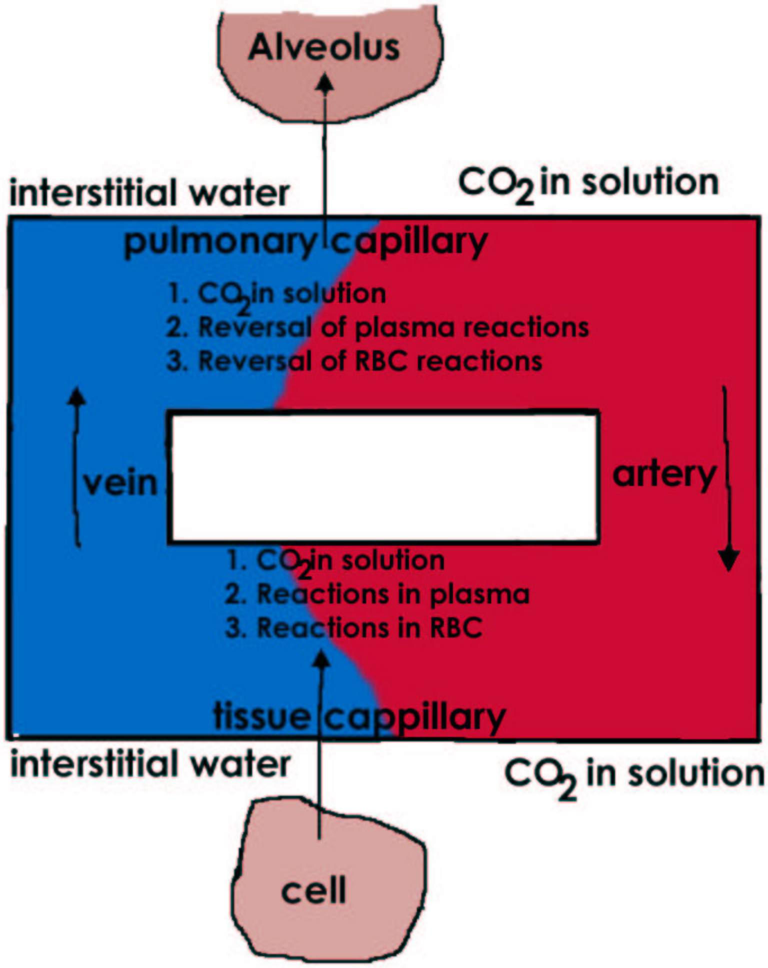
Direction of diffusion for oxygen (O_2), and carbon dioxide (CO_2), as shown by arrows. In the pulmonary alveolus the Pco_2 is 40 mm Hg and the Po_2 is 104 mm Hg; at the arterial end of the pulmonary capillary the Pco_2 is 45 mm Hg and the Po_2 is 40 mm Hg, whereas at the venous end the Pco_2 is 40 mm Hg and the Po_2 is 100mm Hg; at the venous end of the tissue capillary the Pco_2 is 45 mm Hg and the Po_2 40 mm Hg, whereas at the arterial end the Pco_2 is 40 mm Hg and the Po_2 is 100 mm Hg; and in the tissue cell the Pco_2 is 50 mm Hg and the Po_2 is 50 mm Hg and the Po_2 is <30 mm Hg.

D. Oxygen transport
   1. Normal activity consumes about 20% of the oxygen in the blood. The remainder is considered a reserve for increased activity.
   2. Oxygen transport scheme
      a. air to alveolar membrane to interstitial fluid
      b. interstitial fluid to plasma to erythrocyte membrane to erythrocyte fluid to hemoglobin
      c. Oxygen dissolves in the blood only slightly. If the blood contained oxygen only in solution there would need to be 60 times more blood to transport the oxygen required.
      d. hemoglobin reduces the blood required for oxygen transport

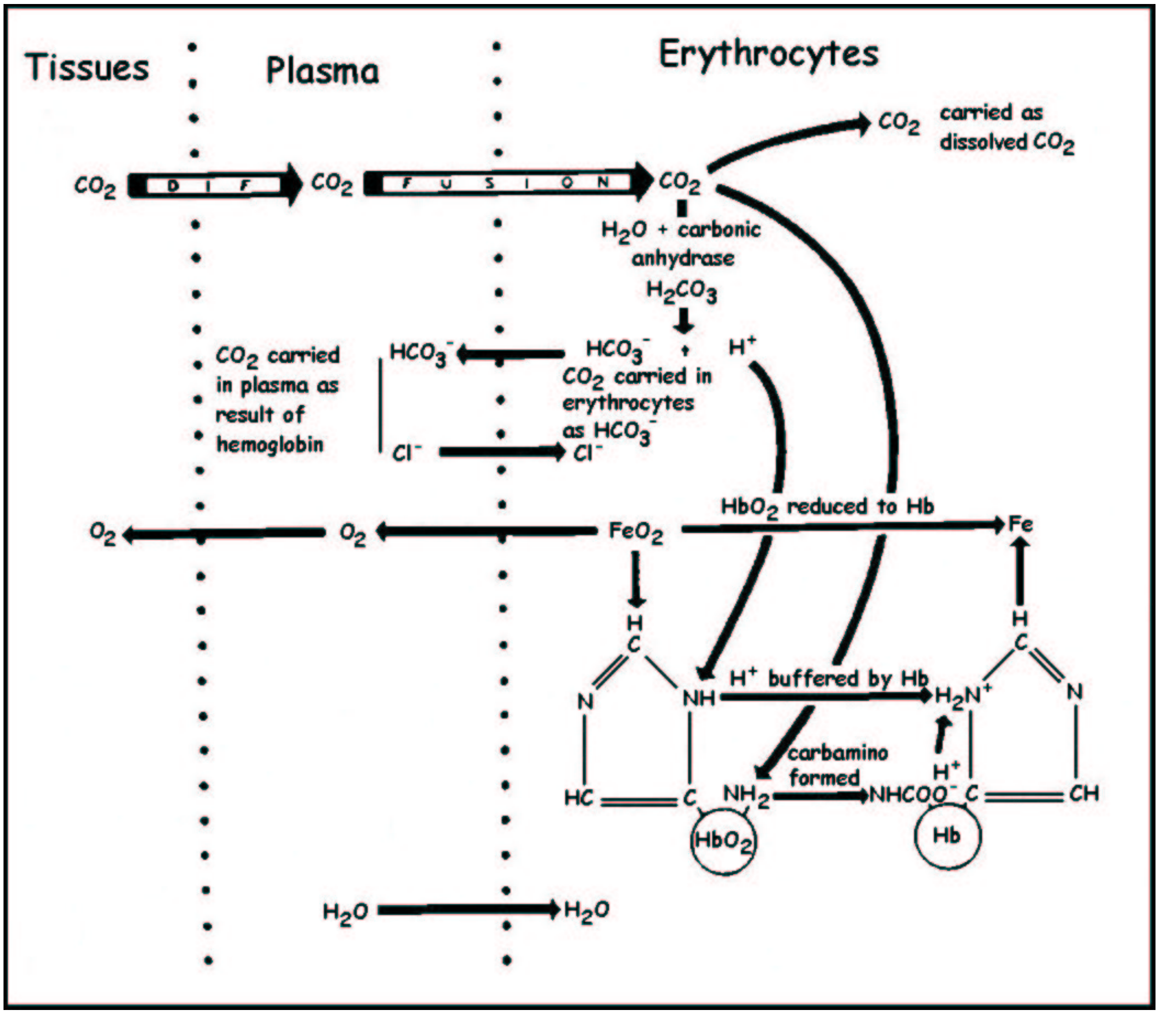


General scheme of oxygen transport showing oxygen procession. Procession occurs because of the presence of pressure gradients. In this diagram, blood is oxygenated at the top and deoxygenated at the bottom; blood flow is clockwise.

E. Transport of carbon dioxide
   1. The transport of carbon dioxide is facilitated by several reactions that effectively provide other carbon dioxide forms in addition to that which is in solution
   2. About 80% of carbon dioxide transport occurs as bicarbonate.
      a. formation results from hydration reaction
      b. reaction is favored in erythrocytes, because of presence of carbonic anhydrase
      c. Another reaction accounting for carbon dioxide transport is the combination of CO_2 with the terminal amino groups on the proteins of plasma and hemoglobin to form carbamino compounds.



General scheme of carbon dioxide transport showing carbon dioxide procession. Procession occurs because of the presence of pressure gradients. In this diagram flow is clockwise; carbon dioxide is taken up from cells at the bottom and removed from blood at the top. Items are numbered in the order of their occurrence.



Schematic representation of the processes that occur when carbon dioxide diffuses from tissues into erythrocytes.

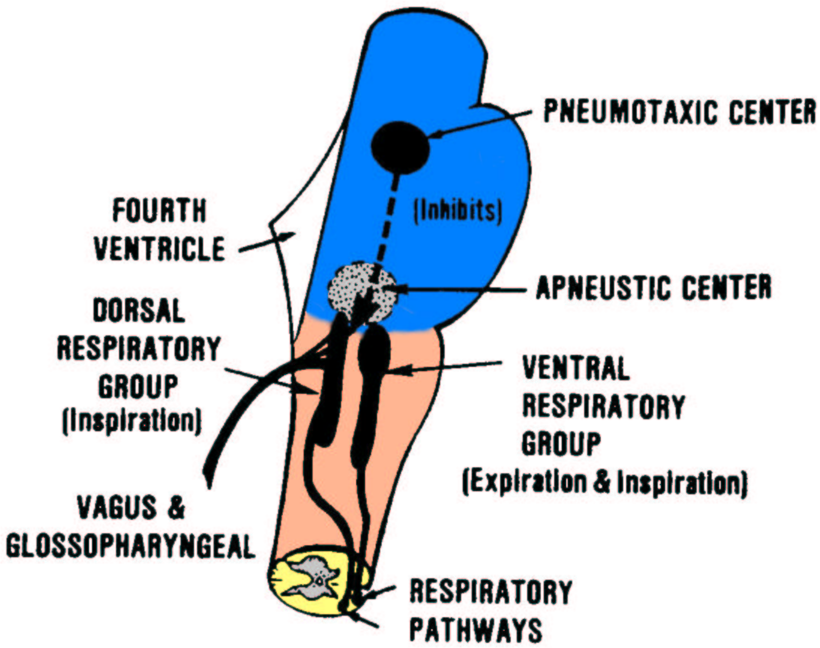
IV. Regulation of Ventilation

A. Pulmonary ventilation is regulated closely to maintain the concentration of H^+, CO_2, and oxygen at relatively constant levels.

B. Regulatory mechanism is located in the brain stem which has four specific regions.

1. pnemotaxic center
2. apneustic center
3. dorsal respiratory group
4. ventral respiratory group

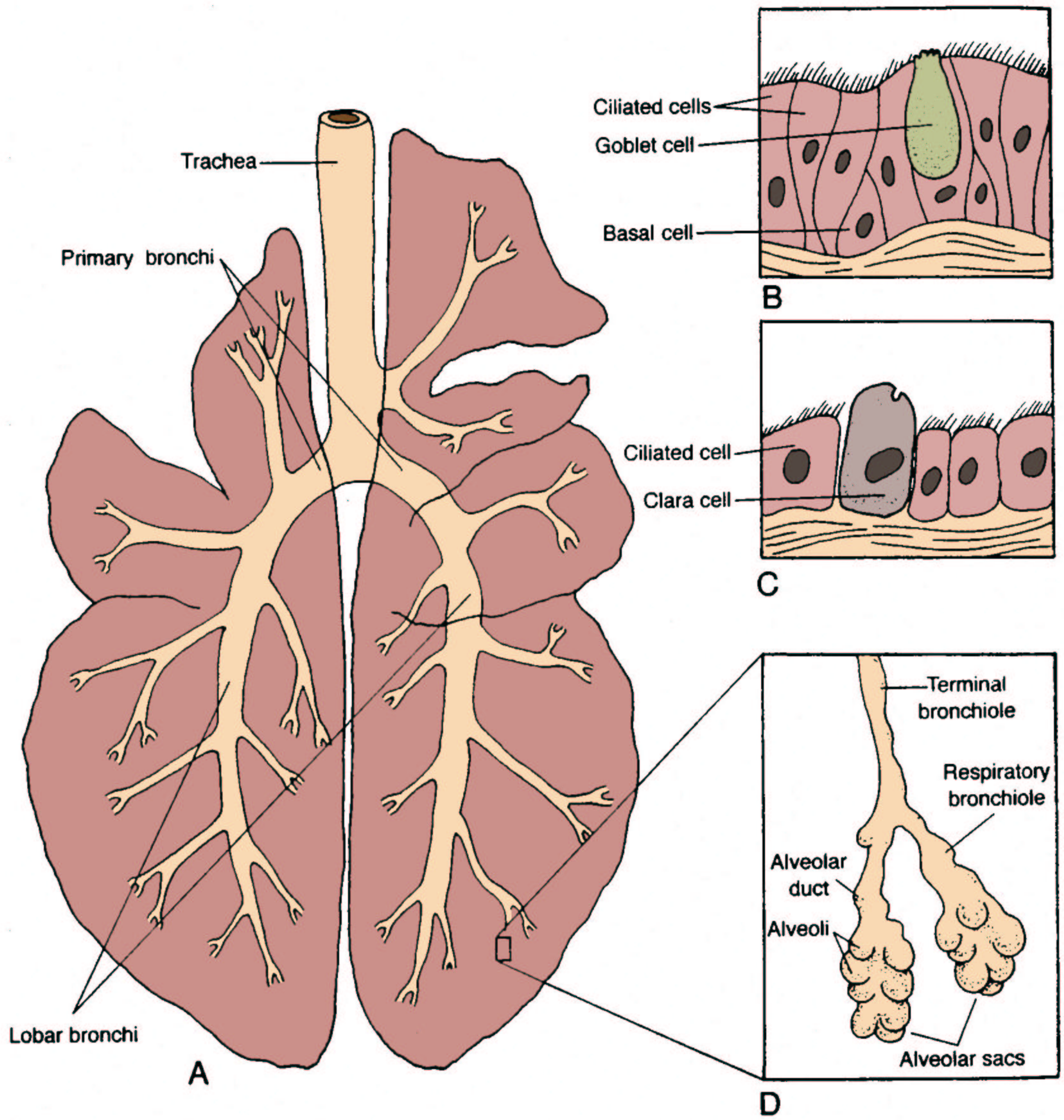
C. Regulation of these centers is both neural and humeral.



Components of the respiratory center. The pneumotaxic and apneustic centers are located in the pons, and the dorsal and ventral respiratory groups are located in the medulla.

V. Respiratory Clearance

A. Surface area of the inner aspects of the lungs is about 125 times larger thatn the surface are of the body.
B. Lungs represent an important route of exposure for many environmental substances.
C. Removal of particles that have been inhaled is called respiratory clearance.
   1. Two types
      a. upper respiratory clearance
         i. accomplished by mucous blanket on the surface of epithelial cells lining airways
      b. alveolar clearance of particles
         i. phagocytized by macrophage
         ii. enter interstitial fluid and transported to lymph nodes
         iii. dissolved and transferred in solution
         iv. stimulate a local connective tissue reaction (asbestos, silicon, carbon)



Contributors to the moving mucous blanket of the bronchial tree. The moving mucous blanket is directed toward the pharynx by the action of the ciliated cells, and the secretion is provided by goblet cells of the bronchi, the Clara cells of the bronchioles, and alveolar fluid. **A.** Outline of the bovine lung superimposed over the bronchial tree. **B.** Pseudostratified epithelium of the bronchi, composed of secretory (goblet) cells, ciliated cells, and basal cells. **C.** Cuboidal epithelium of the terminal bronchioles, composed of ciliated cells and secretory (Clara) cells. **D.** The terminal bronchiole is the most distal air passage free of alveoli.