The Respiratory System

RESPIRATORY ORGANS

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WHAT IS RESPIRATION?

Respiration is the movement of air or dissolved gases into and out of the lungs. It includes two basic processes :-

INHALATION AND EXHALATION

INHALATION is the process of taking in air containing oxygen while

EXHALATION is the process of giving out air rich in carbon dioxide.

Respiration is a biochemical process, where the cells of organisms gain energy by combining oxygen and glucose, which results in giving out carbon dioxide, ATP and water.

TYPES OF RESPIRATION

EXTERNAL RESPIRATION: During external respiration, gaseous exchange takes place between blood and the external environment (with the help of Gills, lungs).

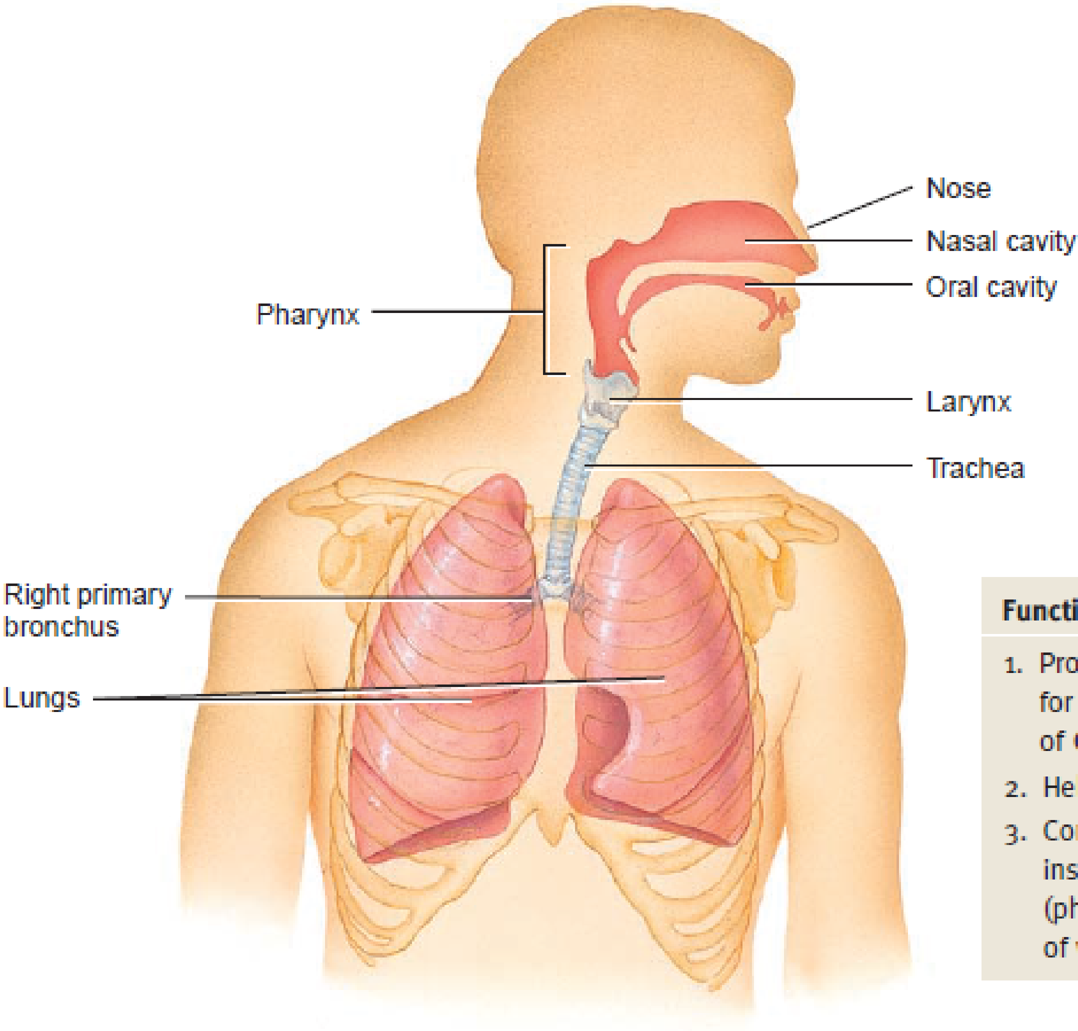
INTERNAL RESPIRATION: During internal respiration, also termed as cellular or tissue respiration, gaseous exchange occur between blood and cells or tissues of the body

PATHWAY OF RESPIRATION IN HUMAN BEINGS

AIR CONDUCTING PORTION : Nose, Pharynx, Larynx, Trachea, Bronchi, Bronchioles

GAS EXCHANGE PORTION : Alveoli (functional unit of the lungs).

Structures of the respiratory system.



(a) Anterior view showing organs of respiration

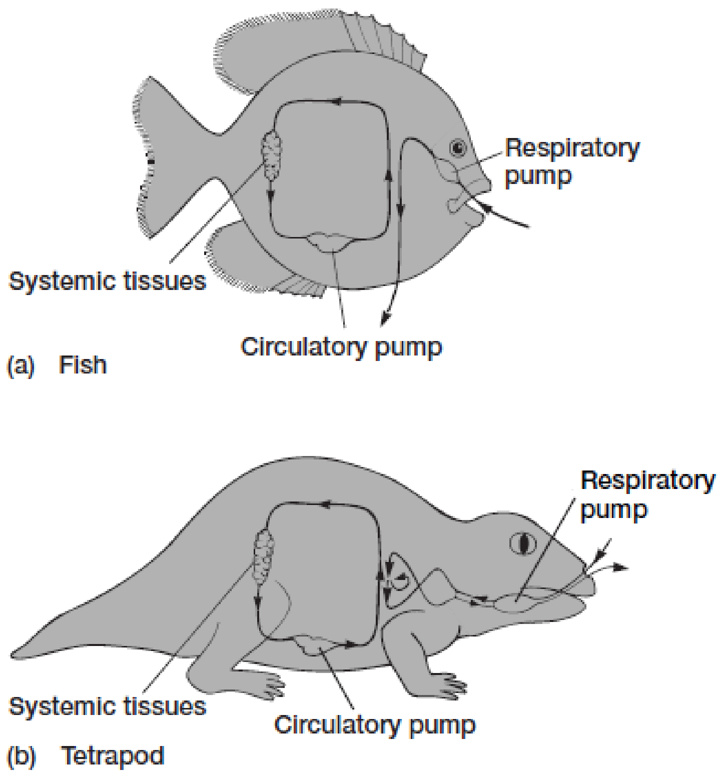
Functions

1. Provides for gas exchange—intake of O_2 for delivery to body cells and elimination of CO_2 produced by body cells.
2. Helps regulate blood pH.
3. Contains receptors for the sense of smell, filters inspired air, produces vocal sounds (phonation), and excretes small amounts of water and heat.

TYPES OF RESPIRATORY ORGANS

Gills
Lungs
Gas Bladders
Cutaneous Respiratory Organs
Accessory Air-breathing Organs
Breathing and Embryos

FIGURE 11.2 Respiratory and circulatory systems cooperate to deliver oxygen to deep tissues and carry away carbon dioxide. Both systems are diagrammed in the figure. During external respiration, air or water is inhaled and transported to the exchange capillaries of the blood. Thereafter, blood circulates oxygen to all systemic (body) tissues, represented here by a small patch of tissue, where internal respiration occurs. Oxygen is delivered to these tissues and carbon dioxide is carried away. (a) In fishes, the respiratory pump usually includes the branchial arches and their musculature. External respiration occurs in the gill capillaries. The heart, being the primary circulatory pump, drives blood through the gills and then to the systemic tissues. (b) In tetrapods, this respiratory pump can include the buccal cavity, which forces air into elastic lungs against resistance, and a rib cage around the lungs. External respiration occurs in the lungs. The circulatory pump, or heart, drives blood through vessels. Internal respiratory exchange occurs between blood and systemic tissues.



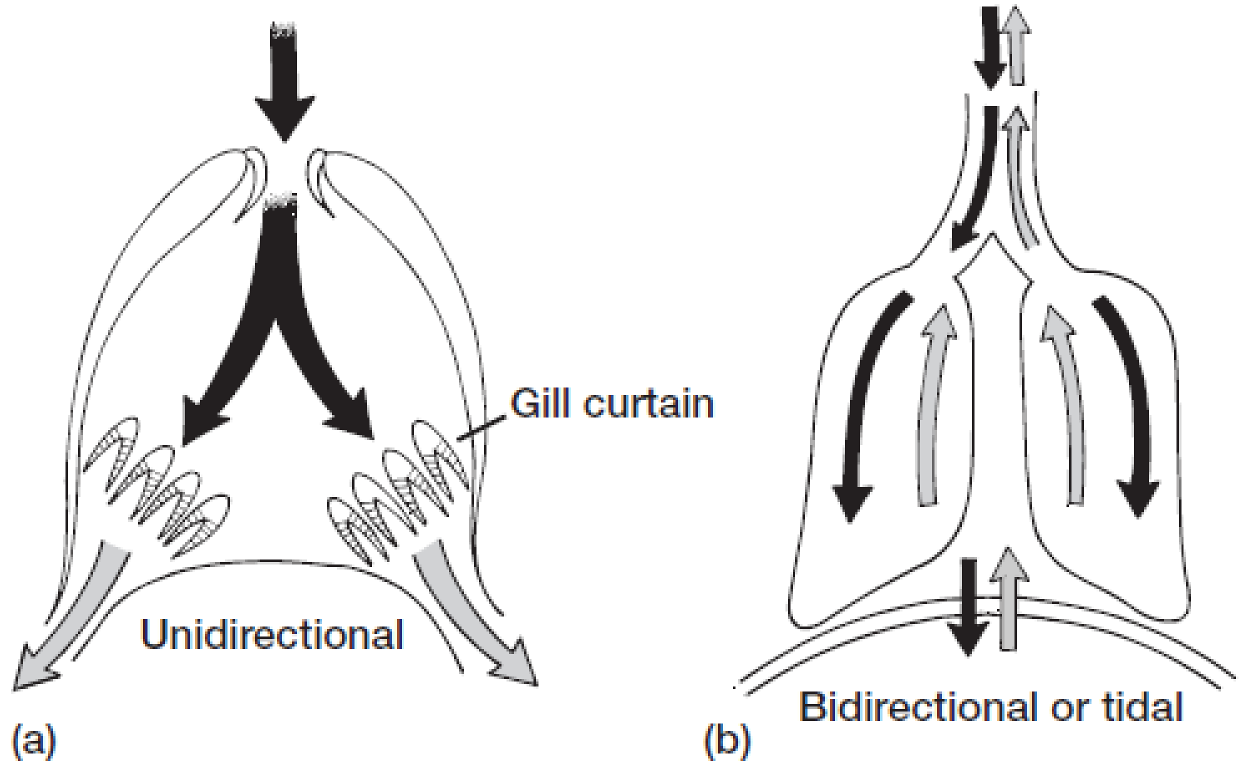


FIGURE 11.3 Unidirectional and bidirectional flow. (a) In fishes and many aquatic amphibians, water movement is unidirectional because water flows through the mouth, across the gill curtain, and out the lateral gill chamber. (b) In many air-breathing vertebrates, air flows into the respiratory organ and then reverses its direction to exit along the same route, creating a bidirectional or tidal flow.

GILLS

Gills are the aquatic respiratory organs of fishes and amphibians. In addition to gaseous exchange, gills may serve for loss or gain of water, and elimination of salts in marine teleosts.

On the basis of their location, gills are of two general types:-

INTERNAL GILLS AND EXTERNAL GILLS.

◆INTERNAL GILLS or TRUE GILLS are characteristic of fishes. They are located in the gill slits and attached to the visceral arches. They may or may not be branched.

◆EXTERNAL GILLS or LARVAL GILLS are formed as branching outgrowths from the exposed outer epithelium of gill arches and not from that of the pharyngeal pouches.

GILLS

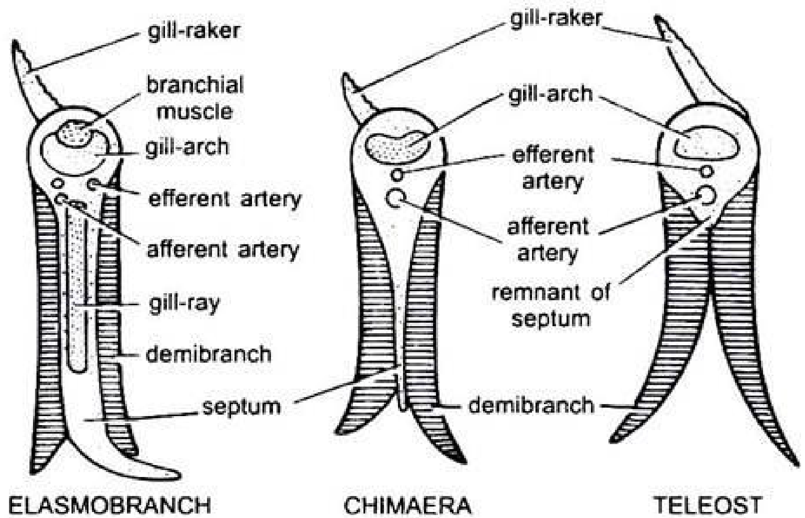


Fig. 44.3. Types of gills in fishes in section.

INTERNAL or TRUE GILLS

- ◆Characteristic of fishes.
- ◆ They are located in the gill slits and attached to the visceral arches.
- ◆ They may or may not be branched.
- ◆GILL SLITS are one of the most fundamental traits of the chordates. The number of gill slits varies in different chordates: 140 in amphioxus, 6-14 pairs in cyclostomes, 5 pairs in most elasmobranchs and bony fishes and 4 pairs in some teleosts. The gill slits are separated from one another by partitions called visceral or gill arches.
- ◆STRUCTURE OF A TRUE GILL: True gills are developed on the walls of some gill clefts or gill arches. Typically, a gill is composed of two rows of numerous gill filaments or lamellae. Gill filaments are richly supplied with blood capillaries and it is here that the exchange of gases with water takes place.

EXTERNAL or LARVAL GILLS

◆EXTERNAL GILLS or LARVAL GILLS are formed as branching outgrowths from the exposed outer epithelium of gill arches and not from that of the pharyngeal pouches.

◆They are ectodermal in origin, and usually temporal organs found only in larval stages, hence also termed larval gills. They occur in the larvae of lampreys, a few bony fishes, and all amphibians.

◆In amphibians, larval external gills are absorbed at the time of metamorphosis but in water-living perennibranchiate urodeles, both external gills and gill slits persists during adult life.

EXTERNAL or LARVAL GILLS

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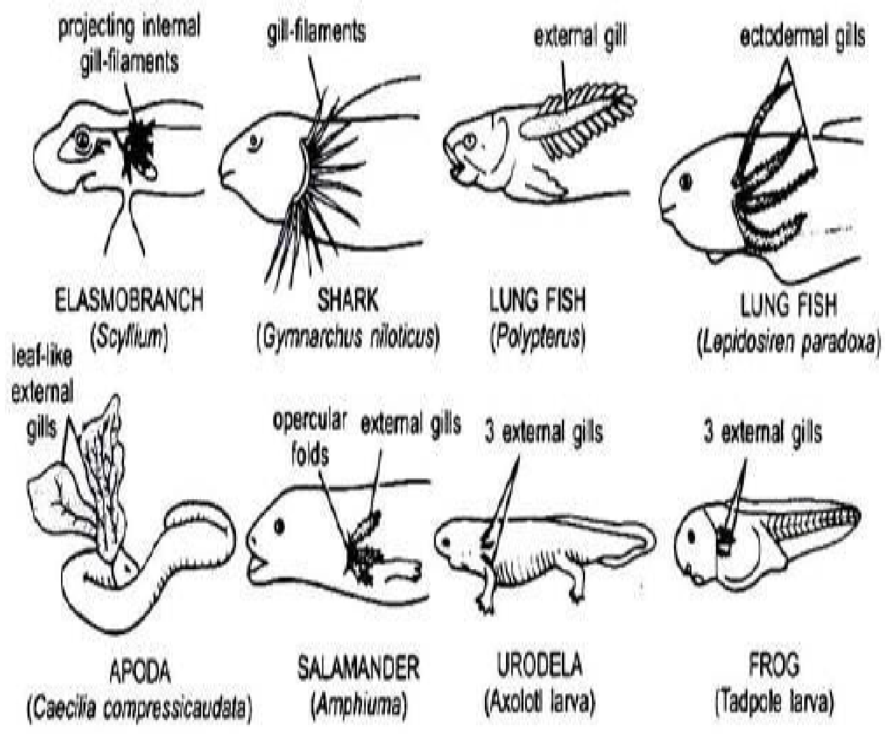
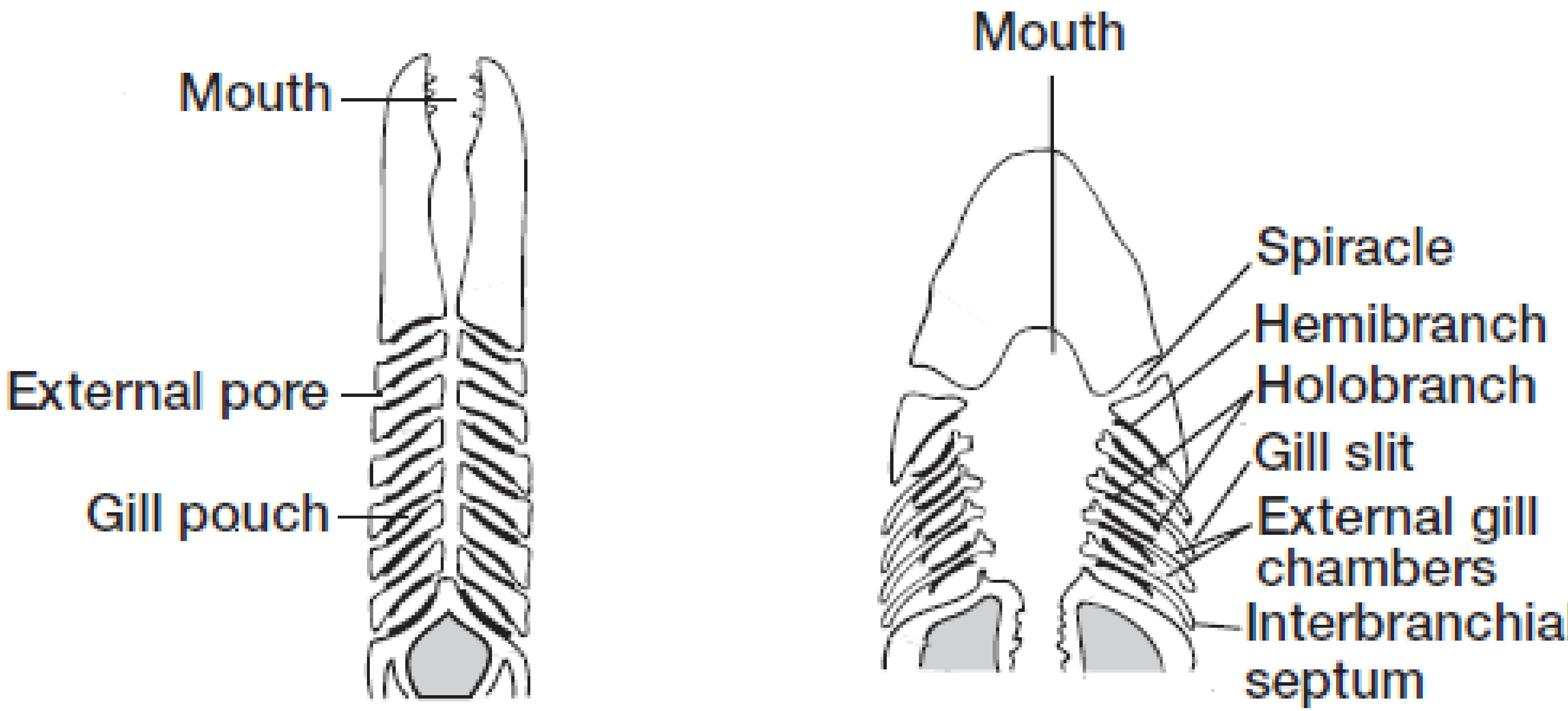
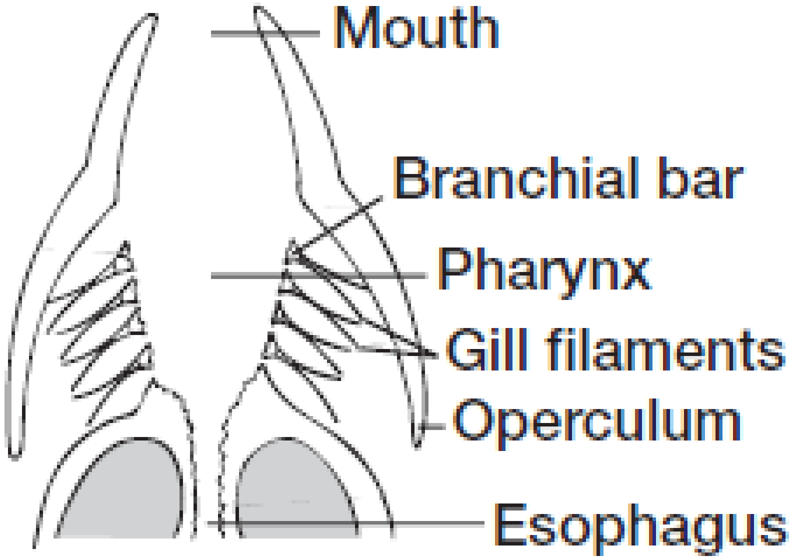


Fig. 44.1. Larval external gills of fishes and amphibians.

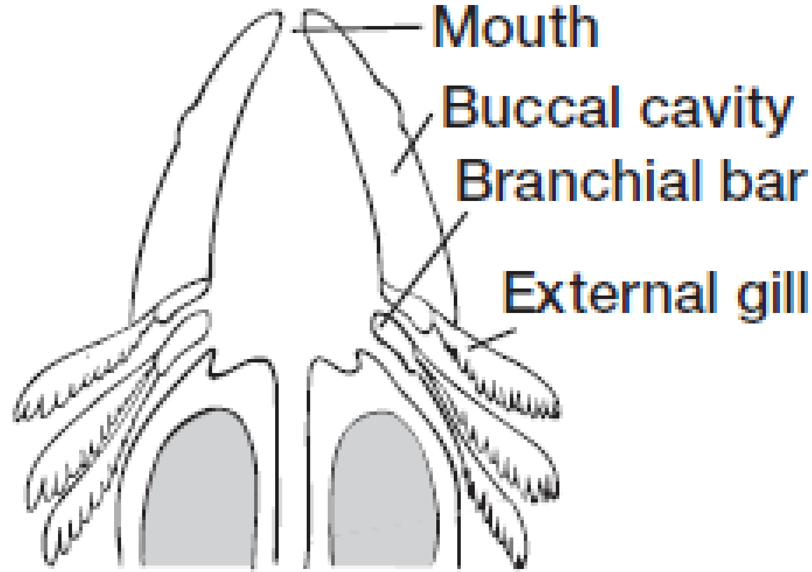


(a) Pouched gills of a lamprey (b) Septal gills of a shark

FIGURE 11.4 Gill coverings. (a) Branchial pouch in lampreys. No cover protects the lateral opening of the gill chamber. (b) Septal gills in sharks. Individual flap valves formed from individual gill septa guard each gill chamber. (c) In most teleosts and



(c) Opercular gills of a teleost



(d) External gills of a larval salamander

individual gill septa guard each gill chamber. (c) In most teleosts and some other species, a common operculum covers their several gills. (d) In larval salamanders, the branchial arches support vascular external gills that project into the surrounding water.

Lungs

Vertebrate lungs are designed for air breathing. Lungs are elastic bags that lie within the body. Their volume expands when air is inhaled and decreases when air is exhaled. Embryologically, lungs arise as endodermal outpocketings from the pharynx. In primitive fishes and most tetrapods, the lungs of adults are usually paired. They lie ventral to the digestive tract and, in amniotes, are connected to the outside environment through the trachea. Entrance into the trachea is gained through the glottis, which is guarded by tiny sets of muscles that open and close it. Usually the trachea branches into two **bronchi, one to each lung. In some** species, each bronchus branches into successively smaller **bronchioles that eventually supply air to the respiratory surfaces** within the lung.

In tetrapods with slender bodies, one lung may be reduced in size; and in some amphisbaenids and most advanced snakes, only a single lung is present. The trachea, bronchi, and bronchioles can hold a significant volume of air. Although exhalation forces most of the spent air from the lungs, some remains in these passageways. Upon inhalation, this "spent" air is drawn back into the lungs before fresh air from outside reaches the lungs to mix with the used air. This volume of used air within the respiratory passageways is called the **dead space.**

The total volume inhaled in a single breath is referred to as the **tidal volume. In a** chicken, the dead space may represent up to 34% of the total tidal volume. Normal tidal volume of a human at rest is about 500 ml. Because the dead space is about 150 ml (30%), 350 ml (500 ml–150 ml) of fresh air actually reaches the lungs

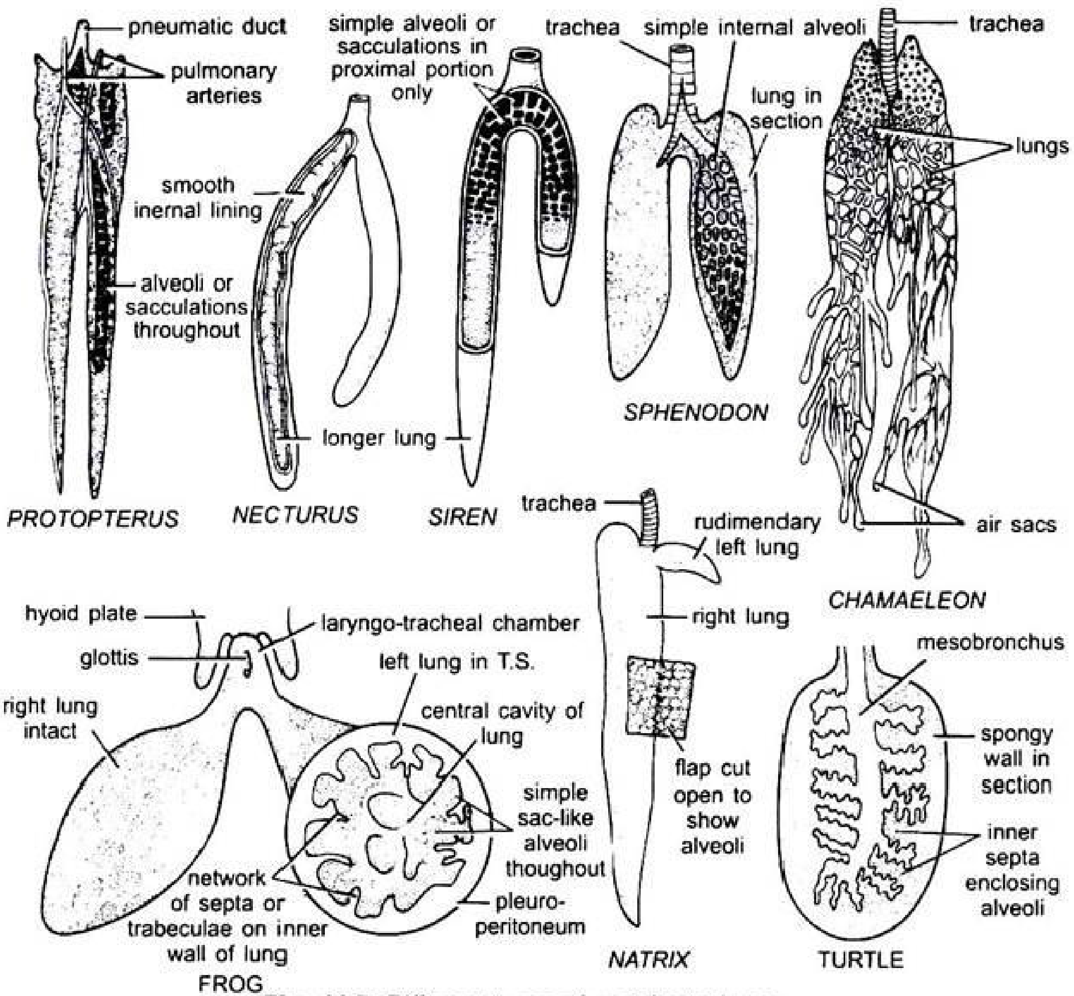


Fig. 44.5. Different types of vertebrate lungs.

Gas Bladders

Many actinopterygian fishes possess a **gas bladder,** a single elongated sac located dorsal to the digestive tract. This bladder sometimes retains a **pneumatic duct,** its tubular connection to the digestive tract. Gas bladders are filled with air that enters via the pneumatic duct or with gas secreted into

the bladder from the blood. If used to control the buoyancy of the fish in the vertical water column, they are referred to as **swim bladders.** Occasionally they may be heavily vascularized to participate in supplementary respiration and are called **respiratory gas bladders.** The internal vascular walls of respiratory gas bladders are subdivided into many partitions that increase the surface area available for external respiratory exchange.

Gas bladders differ from lungs in three ways. First, gas bladders are usually situated dorsal to the digestive tract whereas lungs are ventral; and second, gas bladders are single, whereas lungs are usually paired. *Neoceratodus*, the Australian lungfish, is an exception, because as an adult it has a single lung dorsal to the digestive tract; however, its trachea originates ventrally from the digestive tract. Its embryonic lung arises initially as a paired primordium, suggesting that the single lung of *Neoceratodus* is a derived condition. Third, in gas bladders, returning blood drains to the general systemic circulation (cardinal veins) before entering the heart. In lungs, venous return enters the heart separately from the general systemic circulation.

SWIM BLADDER

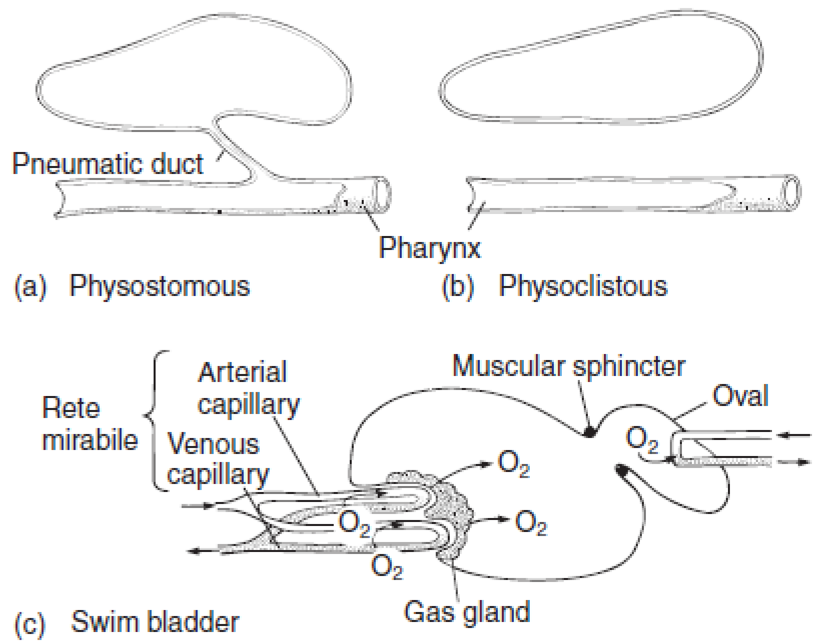
- A characteristic organ of bony fishes is a gas-filled pneumatic sac, called **air bladder or swim bladder**, lying dorsal to the digestive tract, directly beneath the vertebral column and mesonephric kidneys but outside coelom.
- Swim bladder does not occur in elasmobranchs.
- Air bladder generally arises as an outgrowth from the oesophageal region of the alimentary canal. It lies ventral to alimentary canal in Polypterus, laterally in Dipnoi, and dorsally or dorsoventrally in teleosts.
- A typical teleostean air bladder is a thin walled gas filled sac lying dorsally to alimentary canal extending the entire length of body cavity.

FUNCTION OF AIR BLADDER

- **RESPIRATION**: In lower or intermediate fishes, such as ganoids and lung fishes, the air bladder serves as a lung. These fishes come to water surface regularly to gulp air.
- **HYDROSTASIS**: Air bladder in teleosts functions chiefly as a hydrostatic organ and helps to keep the weight of piscine body equal to the volume of water displaced by fish. Secretion of more gases means lower specific gravity so that fishes rise in water. Resorption of gases means increased specific gravity and the fish sinks. Thus, the fish is able to rise or sink and maintain its equilibrium or position in water without any muscular effort.

- **SOUND PRODUCTION:** Some fishes are able to produce sounds with the gases inside air bladder by the use of special muscles attached to the air bladder. Some fishes can produce grunting, hissing or drumming. The circulation of air inside the bladder causes the vibration of incomplete septa, which in turn, produces sound. The sound production is meant to startle the enemies or to attract mates.

- **AUDITION:** In Cypriniformes, a series of small bones, the weberian ossicles, connects the air bladder and perilymph cavity containing internal ear. Low frequency vibrations of the contained gas, induced by noises in water, are transmitted by ossicles to the membranous labyrinth. Thus, these fish can hear.



Swim bladders. (a) Physostomous swim bladders retain their connection to the pharynx via the pneumatic duct. Air volume can be controlled if a fish gulps in more air or releases extra through the pneumatic duct. (b) In the physoclistous swim bladder, the connecting pneumatic duct has been lost. Air volume, and hence buoyancy, is controlled if more gas is released into the bladder at the rete mirabile or if some is removed at the oval. (c) The rete mirabile is a knot of capillaries. As blood leaves the gas gland of the swim bladder via the venous capillaries of the rete, lactic acid is added. This reduces hemoglobin's affinity for oxygen. Oxygen, therefore, tends to diffuse out and enter adjacent arterial capillaries passing blood to the rete. Consequently, the oxygen concentration builds in the arterial blood as it approaches the gas gland so that the partial pressure of oxygen in the arterial capillaries of the rete is high when it reaches the gas gland. This encourages oxygen release into the swim bladder.

Cutaneous Respiratory Organs

Although lungs and gills are the primary respiratory organs, the skin can supplement breathing. Respiration through the skin, referred to as cutaneous respiration, can take place in air, in water, or in both. In the European eel and plaice, oxygen uptake through the skin may account for up to 30% of total gas exchange (figure 11.6). Amphibians rely heavily on cutaneous respiration, often developing accessory skin structures to increase the surface area available for gas exchange. In fact, in salamanders of the family Plethodontidae, adults lack lungs and gills and depend entirely on cutaneous respiration to meet their metabolic needs. Like most mammals, humans respire very little cutaneously, although our skin is permeable to some chemicals applied topically (spread on the surface). In fact, many medicinal ointments are absorbed through the skin. Bats take advantage of cutaneous respiration across their well-vascularized wing membranes to eliminate as much as 12% of their total carbon dioxide waste, but they take up only 1% or 2% of their total oxygen requirement through this cutaneous route (figure 11.6). Feathers and poorly vascularized skin of birds preclude cutaneous respiration. Similarly, in reptiles, the surface covering of scales limits cutaneous respiration. However, in areas between scales (at the hinges of scales) and in areas with reduced scales (e.g., around the cloaca), the skin is heavily vascularized to allow some cutaneous respiration. Sea snakes can supplement up to 30% of their oxygen intake via cutaneous respiration across the skin on their sides and back. Many turtles pass the cold winter in hibernation safely at the bottom of ponds where the limited respiration around their cloaca is sufficient to meet their reduced metabolic needs.

The newly hatched larva of the teleost fish *Monopterus albus*, an inhabitant of southeast Asia, uses predominantly cutaneous respiration during its early life. At hatching, the large and heavily vascularized pectoral fins beat in such a fashion as to drive a stream of water backward across the surface of the larva and its yolk sac. Blood in superficial skin vessels courses forward. This establishes a countercurrent exchange between water and blood to increase the efficiency of cutaneous respiration in this larva (figure 11.7a). Such a respiratory organ allows the larva to inhabit the thin layer of surface water into which nearby oxygen from the air has dissolved. Similarly, in many amphibians, increased surface area allows for increased cutaneous gas exchange (figure 11.7b,c).

Accessory Air-breathing Organs

Lungs and skin are not the only organs that tap sources of oxygen in the air. Many fishes have specialized regions that take up oxygen from the air. *Hoplosternum*, a tropical catfish found in fresh waters in South America, gulps air and swallows it into its digestive tract (figure 11.8a). Oxygen in the gulped air diffuses across the wall of the digestive tract into the bloodstream. The digestive tract is richly supplied with blood vessels that supplement gill respiration. The electric eel *Electrophorus* gulps and holds air in its mouth to expose capillary networks of the mouth to oxygen (figure 11.8d).

Gills ordinarily are unsuitable organs for air breathing. The moist, leaflike exchange surfaces stick together in air and collapse without the buoyant support of water. However, in some fishes, gills are used in air breathing (figure 11.8b). The rockskipper *Mnierpes*, an inhabitant of wave-swept rocky shores of the tropical Pacific coast of Central and South America, occasionally makes brief sojourns onto land to scrounge for food, to evade aquatic predators, and to avoid periods of intense wave action. During these sojourns, it holds gulped air against its gills to extract oxygen. Its gills are reinforced to prevent their collapse during these bouts of air breathing.

Breathing and Embryos

Among anamniotes, respiration generally takes place directly between the surrounding environment and the embryo across the skin. In birds and most reptiles, the embryo is wrapped in extraembryonic membranes and

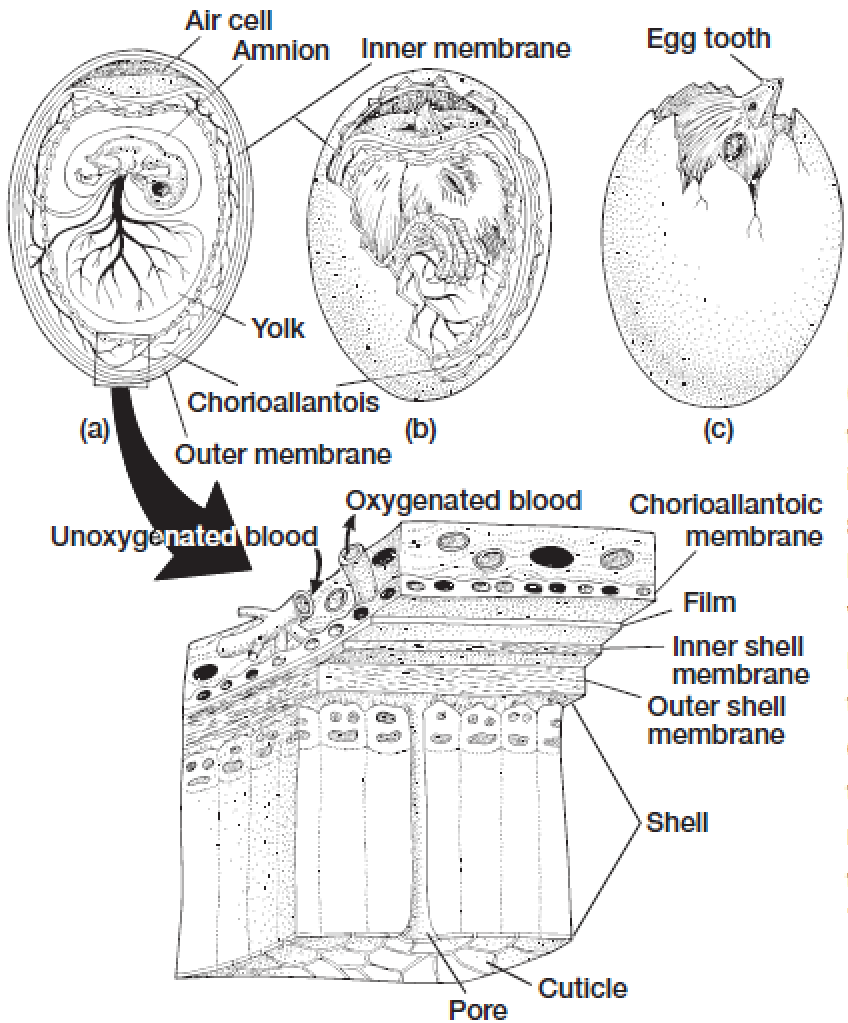


FIGURE 11.9 Respiration in the chicken embryo. (a) While the chick embryo is enclosed in its shell, it respires through this porous shell. The chorioallantois carries blood to the inner surface of the shell to exchange gases at this interface. The shell proper is made up of calcite crystals pierced by tiny pores. Inner and outer shell membranes separate the shell from the vascularized chorioallantois. The chick embryo meets all its respiratory needs, up to day 19 of incubation, as air passes through the porous shell and exchanges gases with blood in the chorioallantois. (b) On day 19, the embryo pokes its beak through the inner shell membrane into the air space between both membranes. Its lungs inflate, and the chick breathes air in addition to continued respiration via the chorioallantois. (c) Six hours later, the chick pecks through the shell proper, a process termed *pipping*, to breathe atmospheric air directly. Thereafter, chorioallantoic respiration declines and the chick further cracks the shell and soon steps out.

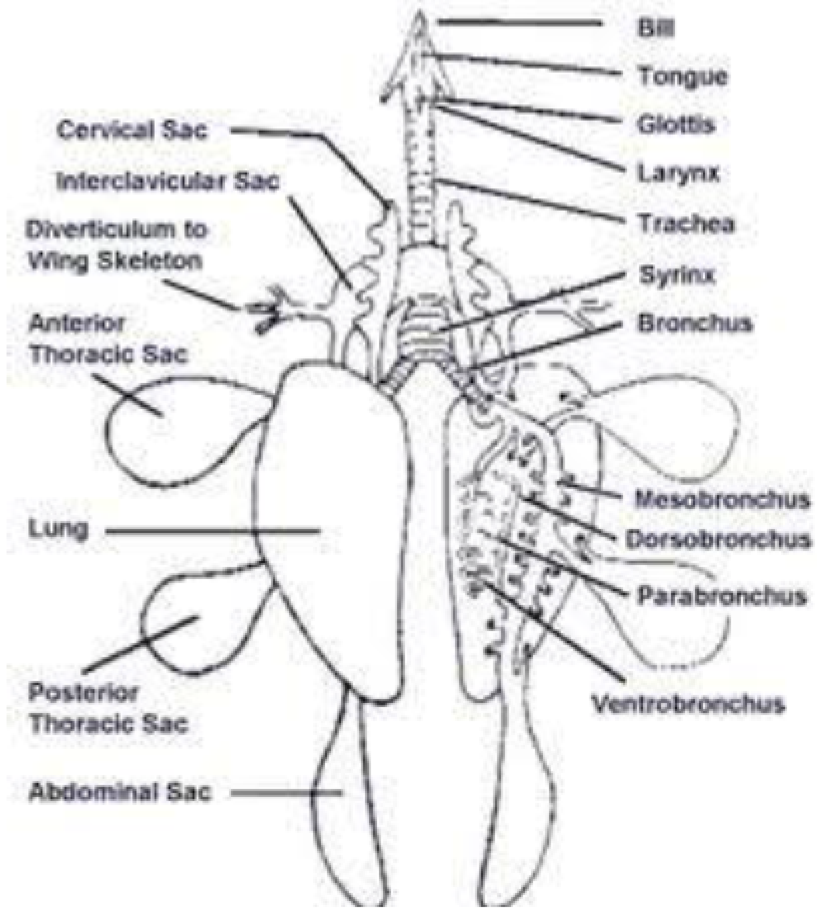
AIR SACS

- A lung component containing air (in birds).
- Large, thin walled, membranous, non-muscular and non-vascular air sacs.
- They lie among the viscera and even extend into some of the larger bones. Their total volume is several times than that of the lungs and they fill up much of the body cavity.
- They arise from the secondary bronchi except the abdominal air sacs. Opening of bronchi into air sacs are termed ostia.
- Air sacs are paired in origin but in pigeon, the two interclavicular air sacs fuse early in development. Thus there are 9 major air sacs in pigeon(a interclavicular, a pair of cervical, two pairs of thoracic and a pair of abdominal air sac).

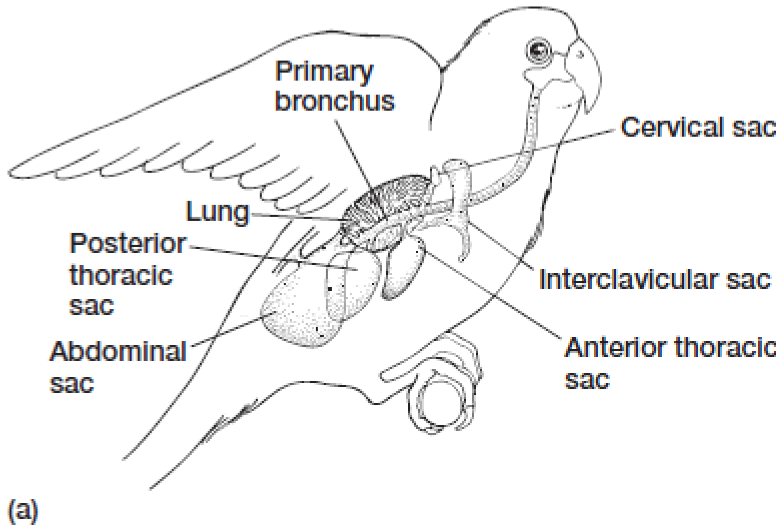
9 MAJOR AIR SACS OF PIGEON

- **INTERCLAVICULAR:** It is a single median and somewhat triangular air sac, connected with both lungs.
- **CERVICAL:** A pair of small cervical sacs arises anteriorly, one from each lung.
- **ANTERIOR THORACIC:** A pair of anterior thoracic air sacs lies ventral to the lungs in the anterior part of the chest, in close contact with the ribs and the pericardium.
- **POSTERIOR THORACIC:** The pair of small posterior thoracic air sacs is found in the posterior part of thoracic cavity, just in front of the abdominal air sacs.
- **ABDOMINAL:** A large posterior or abdominal air sac arises from the outer posterior angle of each lung.

STRUCTURE OF A LUNG AND ORIGIN OF AIR SACS IN PIGEON



Birds



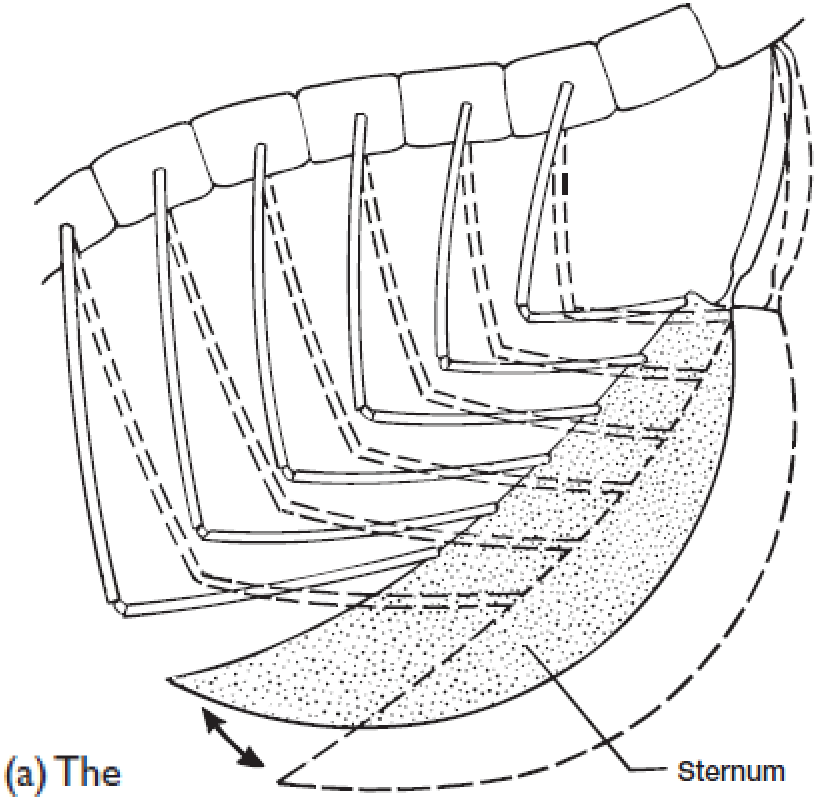


FIGURE 11.35 Avian respiratory system. (a) The respiratory system of birds consists of paired lungs located in the dorsal wall of the thoracic cavity. Air sacs that lie among the viscera and extend into the cores of adjacent bones are attached to the lungs. Apparently the lungs themselves do not change shape with rib cage motion. Rather, compression and expansion of the rib cage acts on the air sacs, drawing air through them and then into the lungs. (b) Ventilation of the avian lung. Ribs are hinged to each other and to the sternum in such a way that lowering of the sternum results in expansion of the rib cage and inhalation. Elevation of the sternum compresses the air sacs and air is expelled.

FUNCTION OF AIR SACS

- **LIGHTNESS:** Act as balloons to provide lightness and buoyancy to the body.
- **FLIGHT:** Their association with flight is also confirmed by the fact that the best fliers amongst birds possess the most highly developed air sacs.
- **BALANCING:** Air sacs are arranged nicely on the two sides of the body so that the proper center of gravity is maintained for the flight.
- **MINIMIZED MECHANICAL FRICTION:** Air sacs and its bronchus are inserted between muscles which reduces mechanical friction during flight.
- **CARDIAC MOVEMENTS:** Another probable function of air sacs, according to Muller, appears to allow for the movement of heart in an otherwise very rigid thorax.

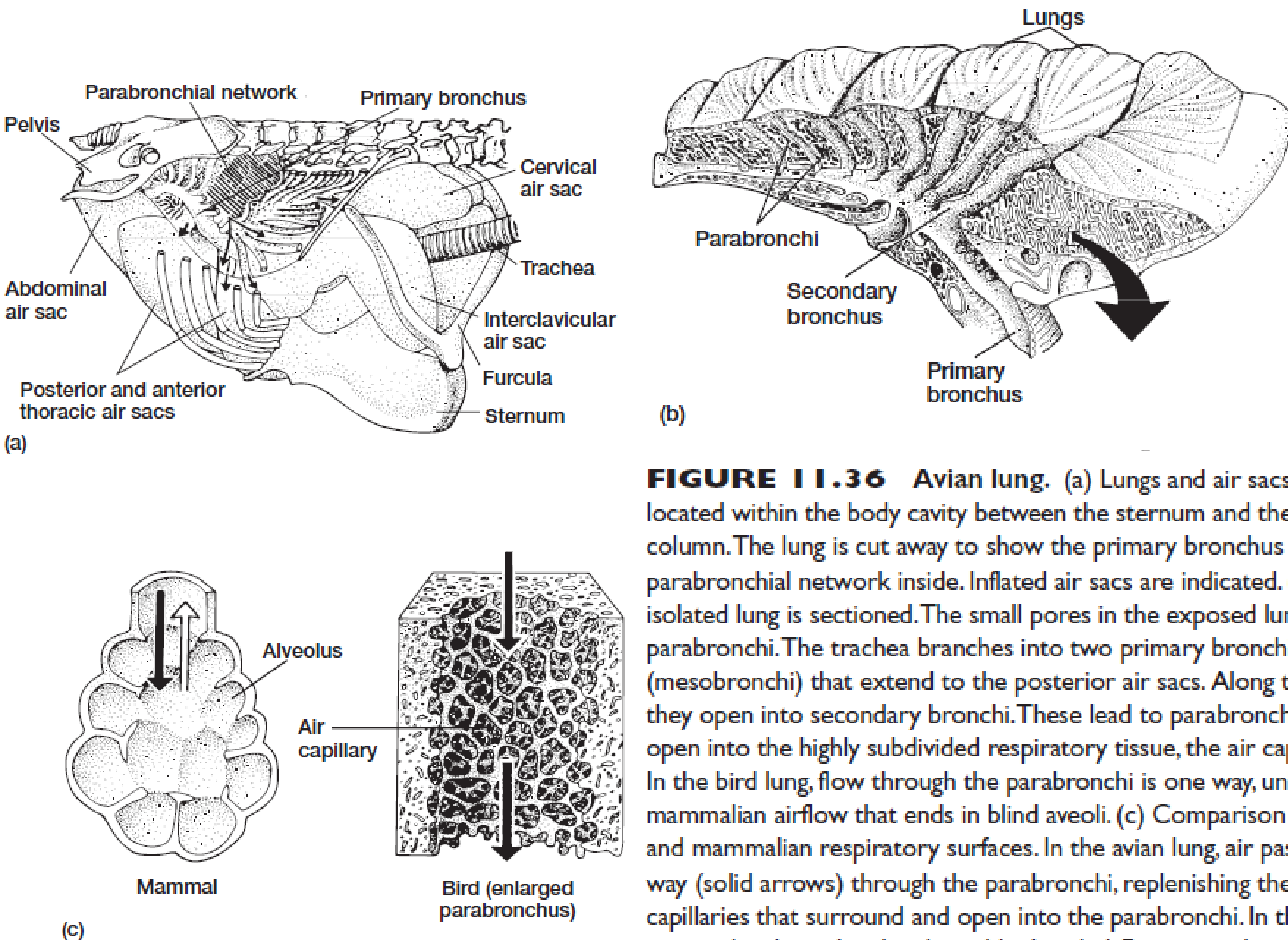


FIGURE 11.36 Avian lung. (a) Lungs and air sacs are located within the body cavity between the sternum and the axial column. The lung is cut away to show the primary bronchus and parabronchial network inside. Inflated air sacs are indicated. (b) The isolated lung is sectioned. The small pores in the exposed lung are parabronchi. The trachea branches into two primary bronchi (mesobronchi) that extend to the posterior air sacs. Along the way, they open into secondary bronchi. These lead to parabronchi that open into the highly subdivided respiratory tissue, the air capillaries. In the bird lung, flow through the parabronchi is one way, unlike the mammalian airflow that ends in blind aveoli. (c) Comparison of avian and mammalian respiratory surfaces. In the avian lung, air passes one way (solid arrows) through the parabronchi, replenishing the air capillaries that surround and open into the parabronchi. In the mammalian lung, the alveoli are blind-ended. For gas exchange to take place, the air must move tidally (open and solid arrows).

Reptiles

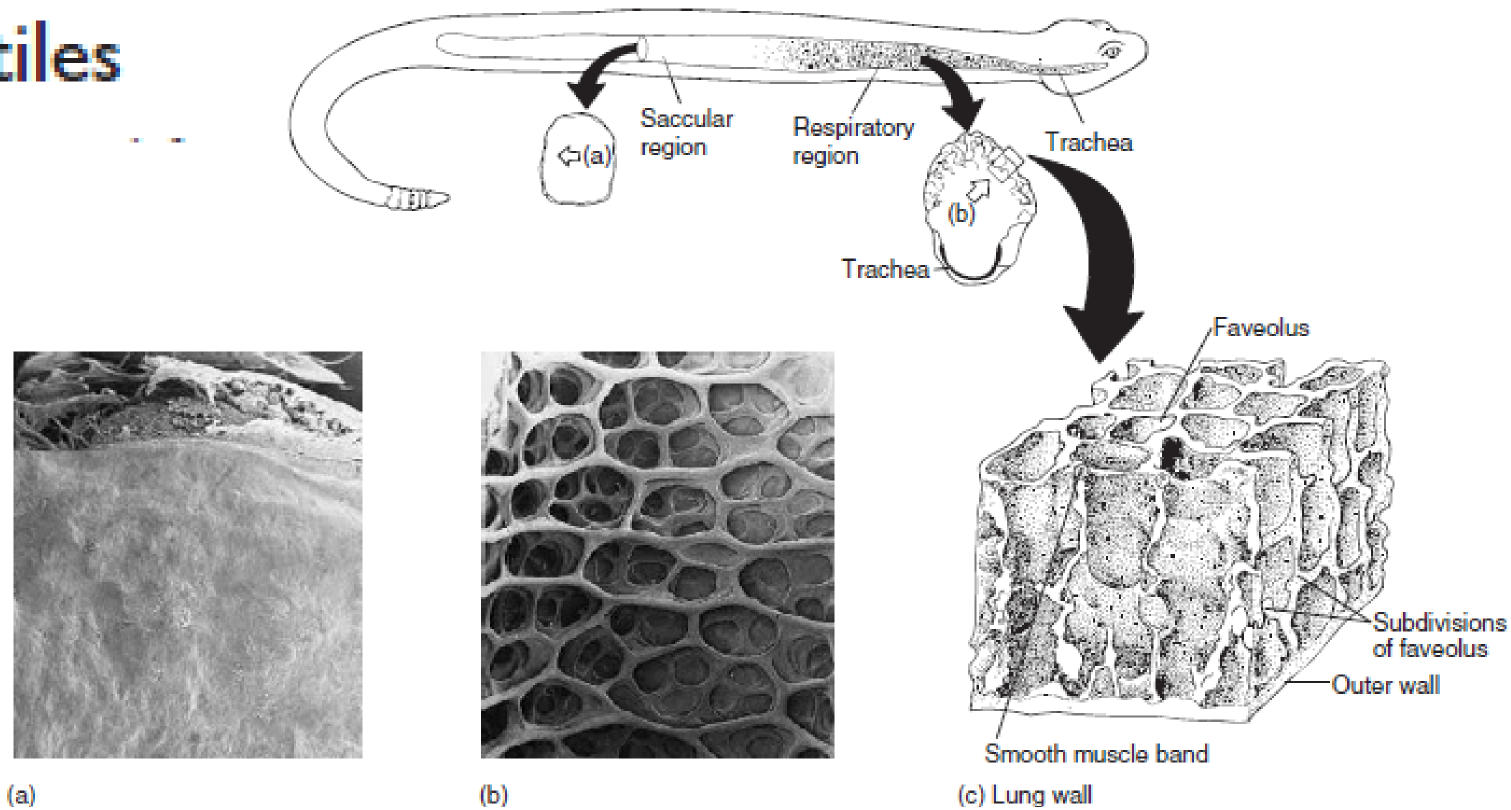


FIGURE 11.27 Snake lung, rattlesnake. Like the snake body, the rattlesnake's one lung is long and attenuated. Air travels down the long trachea to the lung. Most snakes have two lungs of unequal length, but in many venomous snakes, the left lung is lost. The trachea of the rattlesnake lung becomes an open trough where it meets the lung. The anterior lung is heavily vascularized and functions in respiratory exchange. The posterior part of the lung basically is a saccular, avascular region. Ribs along the sides of the body compress and expand to empty or fill the lungs. As the snake swallows prey, the tip of the trachea is pushed in front of the prey, so breathing continues. As the prey moves along the esophagus, which parallels the trachea, the anterior ribs expand to allow passage. At this time, they cannot compress and expand the anterior lung. Therefore, the posterior ribs act upon the saccular region of the lung, working like a bellows to move air across the respiratory surfaces. Representative cross sections of saccular and respiratory regions are illustrated at the top of the figures. Views shown in photos (a) and (b) are indicated in the cross section of the snake lung at the top. (a) Luminal view of the surface of the saccular region. (b) Luminal view of the respiratory region showing the faveoli. The entrance to each faveolus is defined by a honeycombed network of smooth muscles. (c) A section of wall from the respiratory region showing further subdivisions within the faveoli.

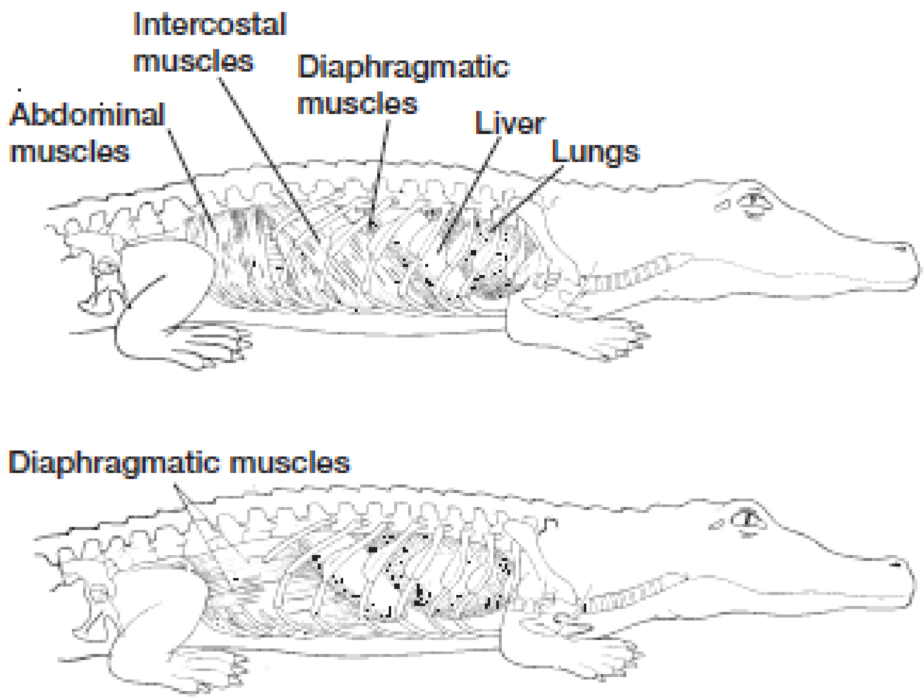


FIGURE 11.28 Ventilation in the crocodile. In addition to a rib cage, the aspiration pump in the crocodile uses back-and-forth movements of the liver like a piston to act on the lungs. During inhalation, the rib cage expands and the liver is pulled back while the crocodile aspirates fresh air into its lungs. During exhalation, the rib cage and forward-moving liver compress the lungs and the crocodile expels spent air.

After Pooley and Gans.

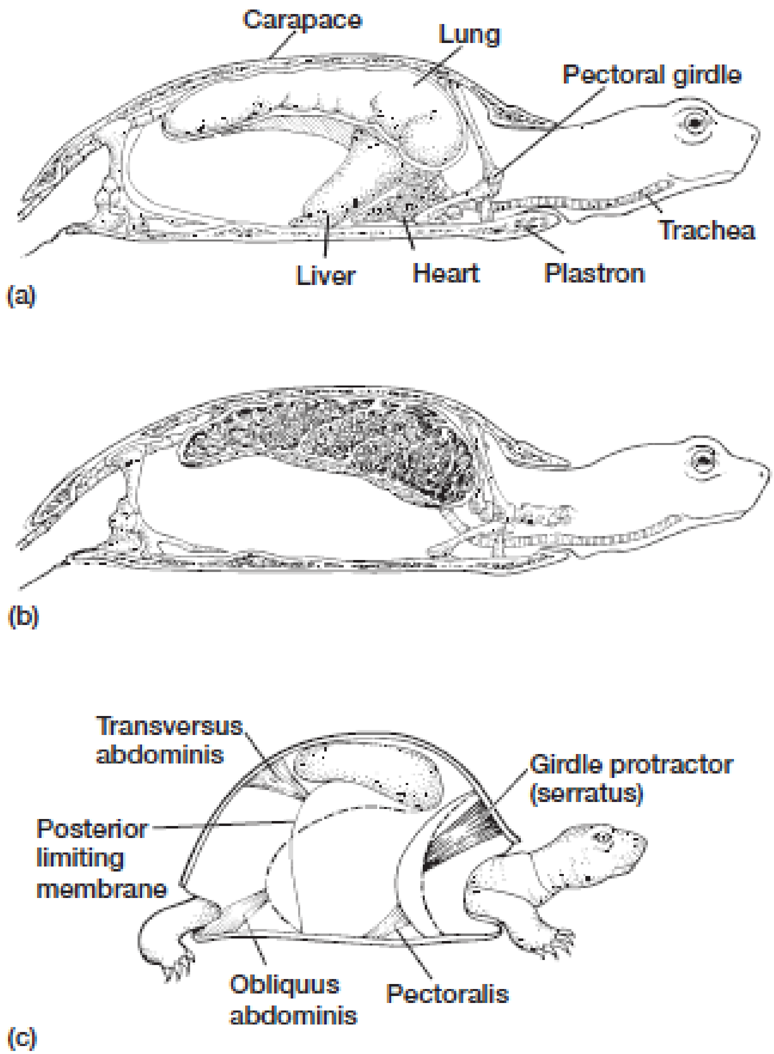


FIGURE 11.29 Ventilation in the turtle. (a) Location of the lung inside the turtle shell. (b) Cutaway view of the lung showing its internal structure. Turtle lungs lie within a protective, rigid shell. Consequently, the fixed rib cage cannot act in ventilating the lungs. Instead, turtles have sheets of muscles within the shell that contract and relax to force air in and out of the lungs. Turtles also have the ability to alter air pressure within the lungs by moving their limbs in and out of the shell. (c) In the specialized tortoise, a diaphragmatic muscle is absent but other respiratory muscles take its place. Within the rigid shell, the viscera are enclosed by limiting membranes that under muscle action alter their position during exhalation (solid line) and inhalation (dashed line). During active exhalation, contraction of the transversus abdominis pulls the posterior limiting membrane up against the lung and contraction of the pectoralis draws the shoulder girdle back into the shell, further compressing the viscera. During active inhalation, exhalation muscles relax and contraction of the obliquus abdominis and girdle protractor expand the visceral cavity by pulling the posterior limiting membrane outward and the shoulder girdle forward, respectively.

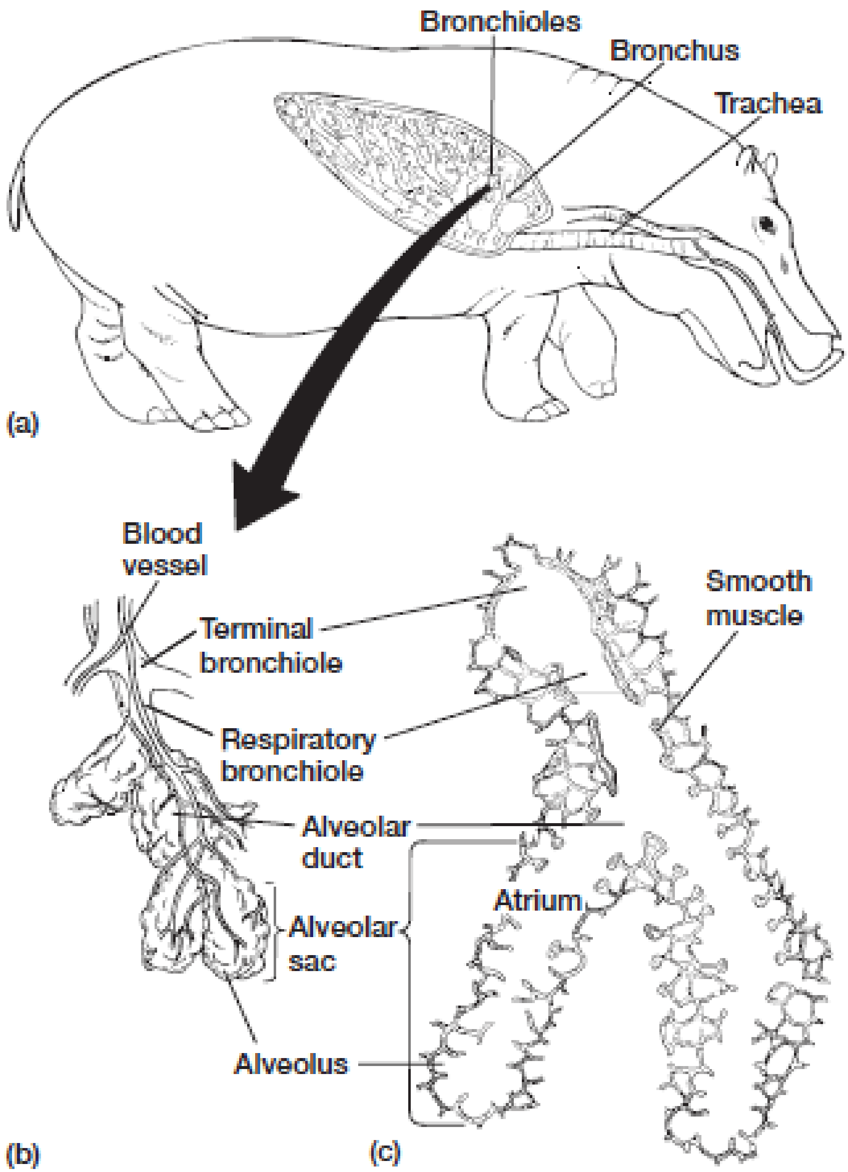
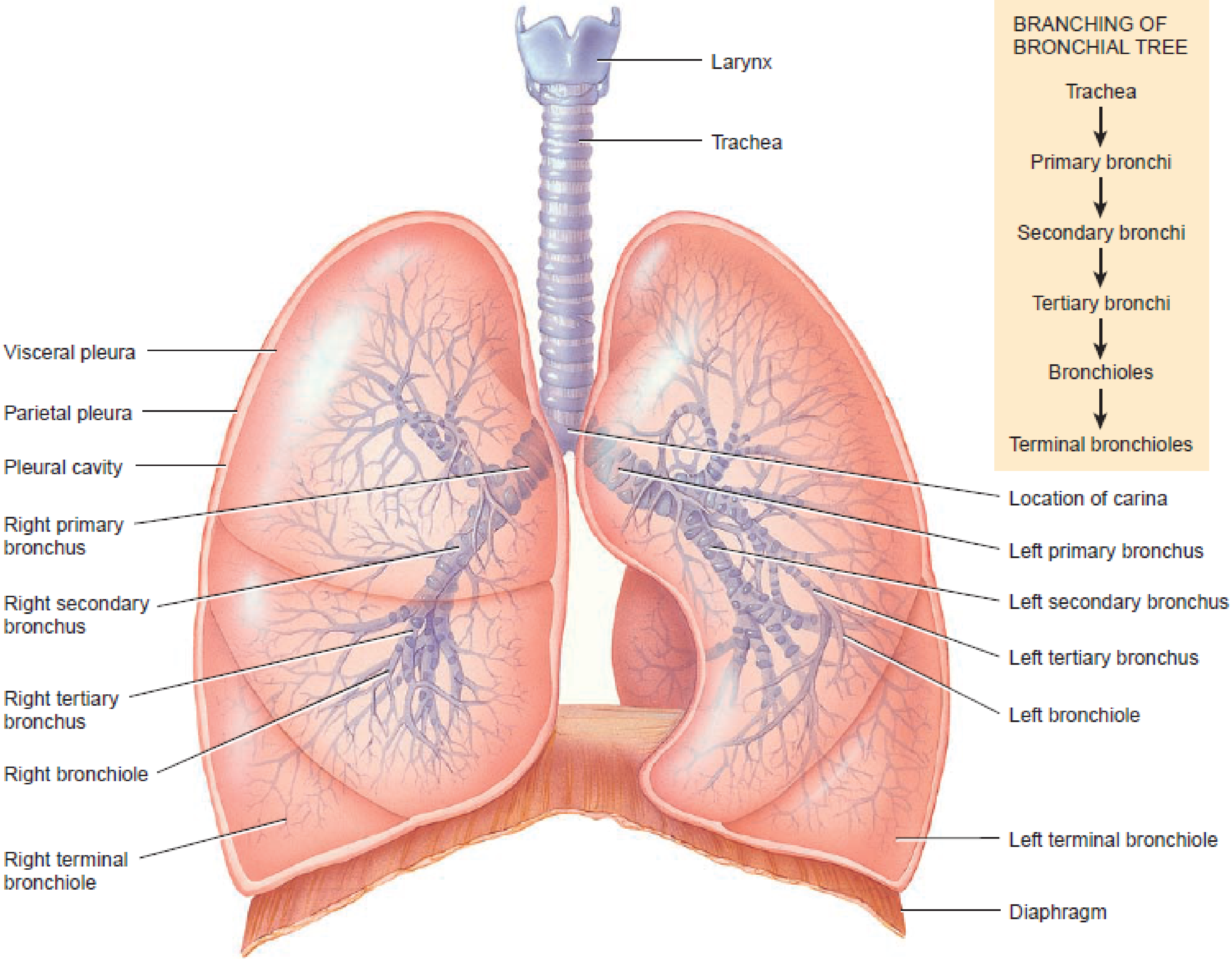
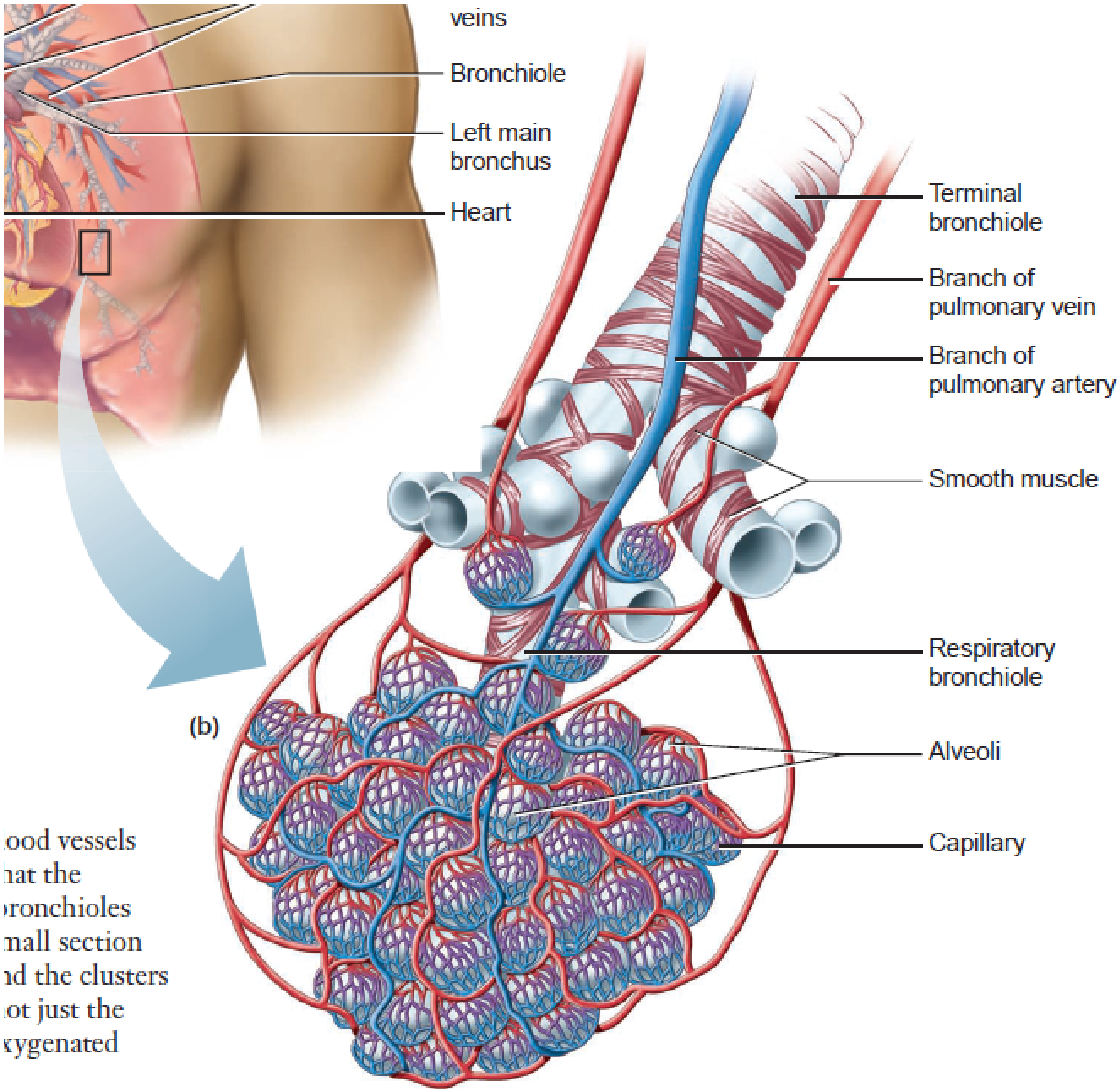


FIGURE 11.34 Mammalian lung. The lungs of mammals are blind-ended, terminating in small alveoli. (a) The trachea leads to the pleural cavities and branches into bronchi to supply left and right lungs. Repeated bronchial branchings produce smaller and smaller bronchioles that eventually lead to alveolar sacs. (b) Enlarged alveolar sac. Arteries and veins supply the alveoli to accommodate gas exchange within them. (c) Internal subdivisions of the alveolar sacs are shown. Each small compartment is an alveolus where actual respiratory exchange between blood and air occurs. Note the smooth muscle bands at the openings to the alveolar sacs.



Anterior view



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