Course: Animal form and function

CHAP : CIRCULATION, IMMUNITY, AND GAS EXCHANGE

- INTERNAL TRANSPORT AND CIRCULATORY SYSTEMS IN INVERTEBRATES
- TRANSPORT SYSTEMS IN VERTEBRATES, BLOOD, BLOOD CELLS AND BLOOD VESSELS.
- BLOOD PRESSURE AND LYMPHATIC SYSTEM
- THE IMMUNE RESPONSE
- GAS EXCHANGE
- RESPIRATORY SURFACES
- INVERTEBRATES AND VERTEBRATES RESPIRATORY SYSTEMS.

THE HEARTS AND CIRCULATORY SYSTEMS OF BONY FISHES, AMPHIBIANS, AND REPTILES

- The heart and blood vessels changed greatly as vertebrates moved from water to land and as endothermy evolved.
- The bony fish heart has two chambers—the atrium and ventricle.
- blood only passes through the heart once, this system is called a single circulation circuit.
- In amphibians and reptiles, the evolution of a double circulatory circuit, in which blood passes through the heart twice during its circuit through the body, has overcome the slow blood-flow problem.

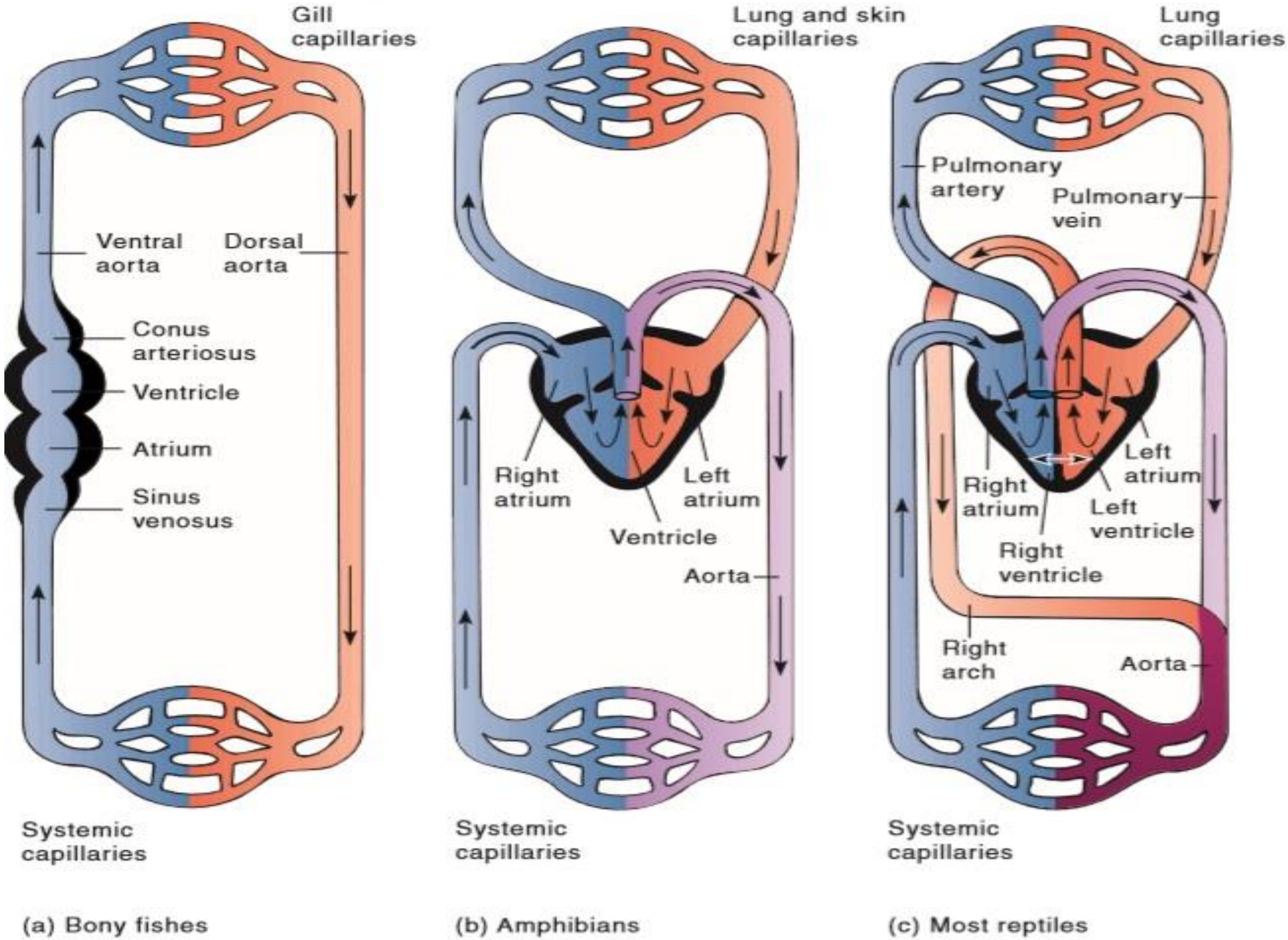


Fig: Heart and Circulatory Systems of Various Vertebrates

THE HEARTS AND CIRCULATORY SYSTEMS OF BIRDS AND MAMMALS

- **Blood circulates throughout the avian and mammalian body in two main circuits: the pulmonary and systemic circuits.**

1) The pulmonary circuit → supplies the blood only to the lungs. It carries oxygen-poor (deoxygenated) blood from the heart to the lungs, where carbon dioxide is removed, and oxygen is added. It then returns the oxygen-rich (oxygenated) blood to the heart for distribution to the rest of the body.

2) The systemic circuit → supplies all the cells, tissues, and organs of the body with oxygen-rich blood and returns oxygen-poor blood to the heart.

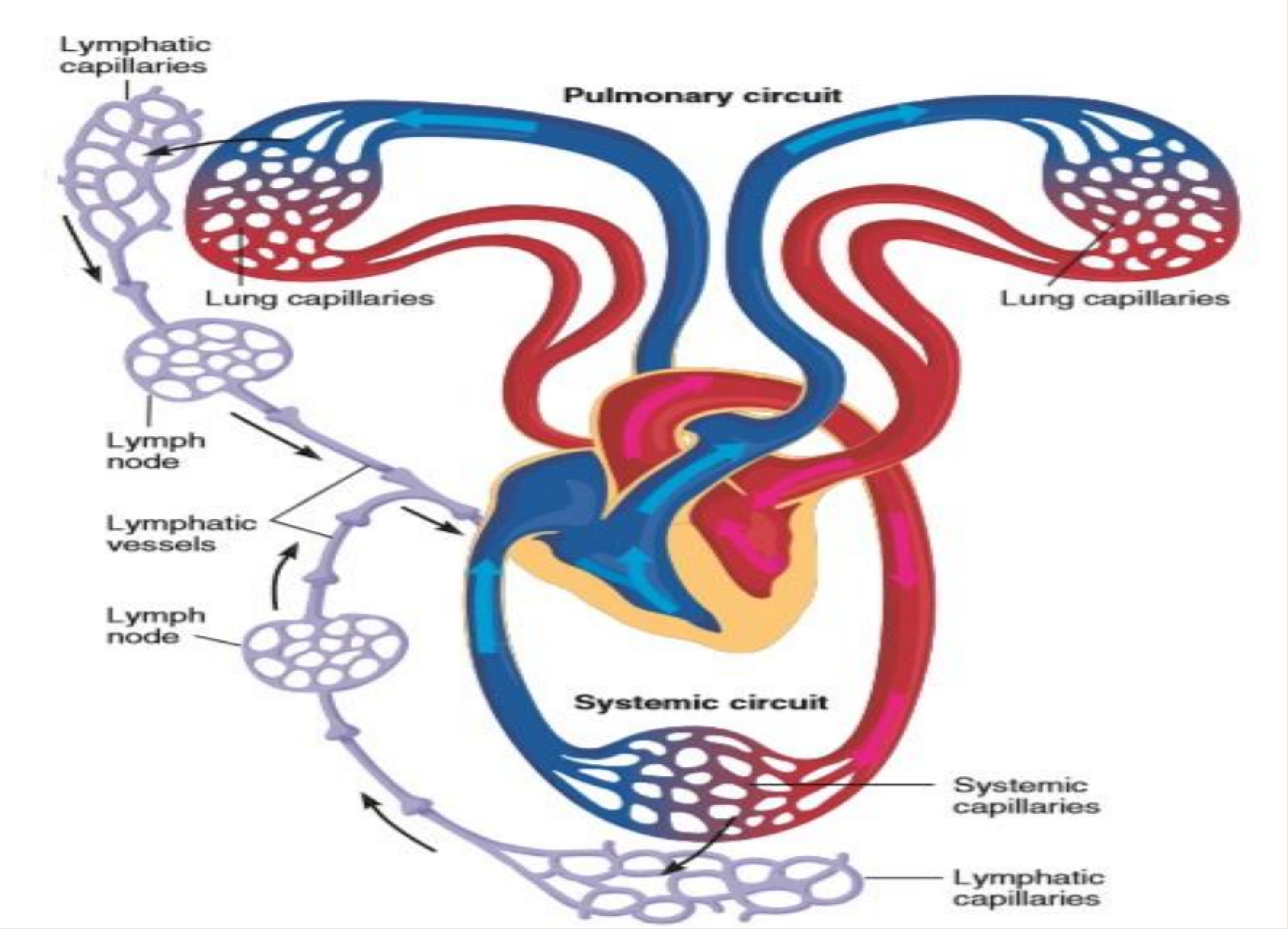


Fig: Circulatory Circuits. The cardiovascular system of a bird or mammal has two major capillary beds and transport circuits: the pulmonary circuit and systemic circuit. The lymphatic system consists of one-way vessels that are also involved in returning tissue fluid, called lymph, to the heart. The black arrows indicate the direction of lymph flow, and the colored (blue and pink) arrows indicate the direction of blood flow.

THE HUMAN HEART

- Most of the human heart is composed of cardiac muscle tissue called **myocardium.**
- The outer protective covering of the heart, however, is fibrous connective tissue called the **epicardium.**
- Connective tissue and endothelium form the inside of the heart, the **endocardium.**
- Less oxygenated blood from the tissues of the body returns to the right atrium and flows through the **tricuspid valve** into the right ventricle.

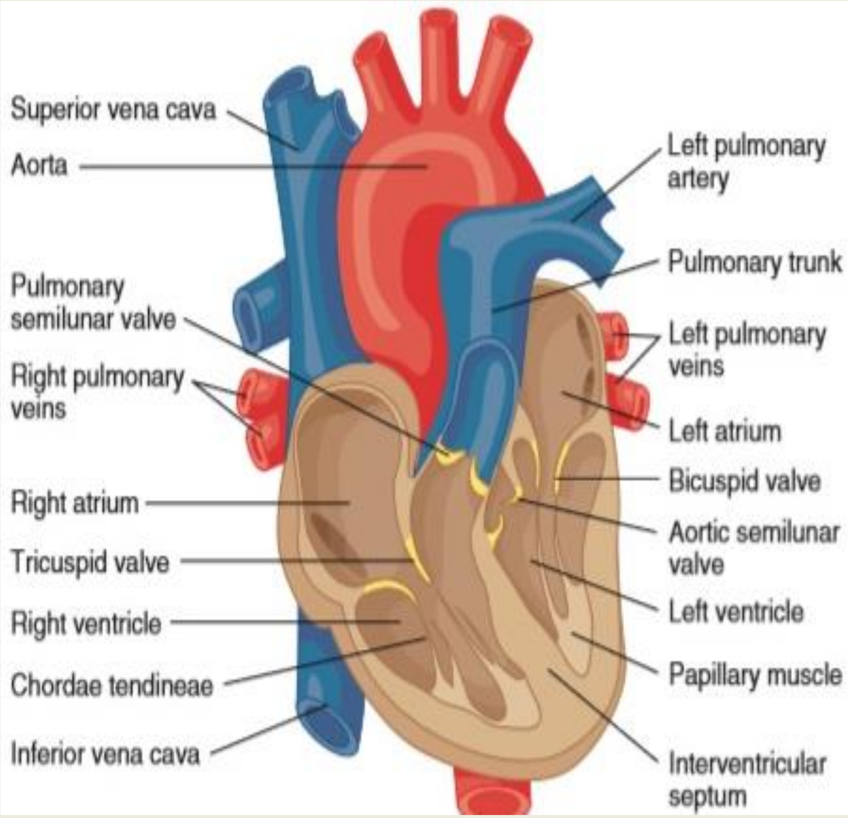


Fig: Structures of the Human Heart.

THE HUMAN HEART

- The right ventricle pumps the blood through the pulmonary semilunar valve into the pulmonary circuit, from which it returns to the left atrium and flows through the bicuspid valve into the left ventricle.
- The left ventricle then pumps blood through the aortic semilunar valve into the aorta.
- The action potential moving over the surface of the heart causes current flow, and can be recorded as an electrocardiogram (ECG or EKG).
- During each cycle, the atria and ventricles go through a phase of contraction called systole and a phase of relaxation called diastole.

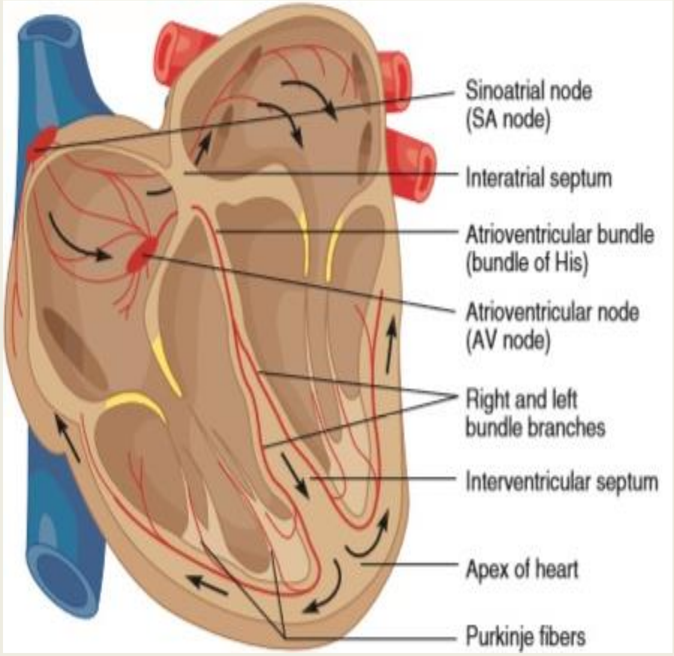


Fig: Electrical Conduction System of the Human Heart. The SA node initiates the depolarization wave, which passes successively through the atrial myocardium to the AV node, the atrioventricular bundle, the right and left bundle branches, and the Purkinje fibers in the ventricular myocardium. Black arrows indicate the direction of the electrical current flow.

BLOOD PRESSURE

- **Ventricular contraction generates the fluid pressure, called blood pressure, that forces blood through the pulmonary and systemic circuits.**

- **The maximum pressure achieved during ventricular contraction is called the systolic pressure.**

- **When the ventricles relax (ventricular diastole), the arterial pressure drops, and the lowest pressure that remains in the arteries before the next ventricular contraction is called the diastolic pressure.**

lymphatic system

The vertebrate lymphatic system begins with small vessels called lymphatic capillaries, which are in direct contact with the extracellular fluid surrounding tissues.

The system has four major functions:

(1) to collect and drain most of the fluid that seeps from the bloodstream and accumulates in the extracellular fluid;

(2) to return small amounts of proteins that have left the cells;

(3) to transport lipids that have been absorbed from the small intestine; and

(4) to transport foreign particles and cellular debris to disposal centers called lymph nodes.

MAJOR STRUCTURAL AND FUNCTIONAL COMPONENTS OF THE LYMPHATIC SYSTEM IN VERTEBRATES

STRUCTURE	FUNCTION
Lymphatic capillaries	Collect excess extracellular fluid in tissues
Lymphatics	Carry lymph from lymphatic capillaries to veins in the neck, where lymph returns to the bloodstream
Lymph nodes	House the WBCs that destroy foreign substances; play a role in antibody formation
Spleen	Filters foreign substances from blood; manufactures phagocytic lymphocytes; stores red blood cells; releases blood to the body when blood is lost
Thymus gland (in mammals)	Site of antibodies in the newborn; is involved in the initial development of the immune system; site of T-cell differentiation
Bursa of Fabricius (in birds)	A lymphoid organ at the lower end of the alimentary canal in birds; the site of B-cell maturation

GAS EXCHANGE

To take advantage of the rich source of energy that earth's organic matter represents, animals must solve two practical problems:

1) **They must break down and digest the organic matter so that it can enter the cells that are to metabolize.**
2) **They must provide cells with both an adequate supply of oxygen required for aerobic respiration and a way of eliminating the carbon dioxide that aerobic respiration produces.**

RESPIRATORY SURFACES

- Simple diffusion across plasma membranes
- Tracheae
- Cutaneous (integument or body surface) exchange
- Gills
- Lungs

INVERTEBRATE RESPIRATORY SYSTEMS

- In single-celled protists, such as protozoa, diffusion across the plasma membrane moves gases into and out of the organism.

- Some multicellular invertebrates either have very flat bodies (e.g., flatworms) in which all body cells are relatively close to the body surface or are thin-walled and hollow (e.g., Hydra). Gases diffuse into and out of the animal.

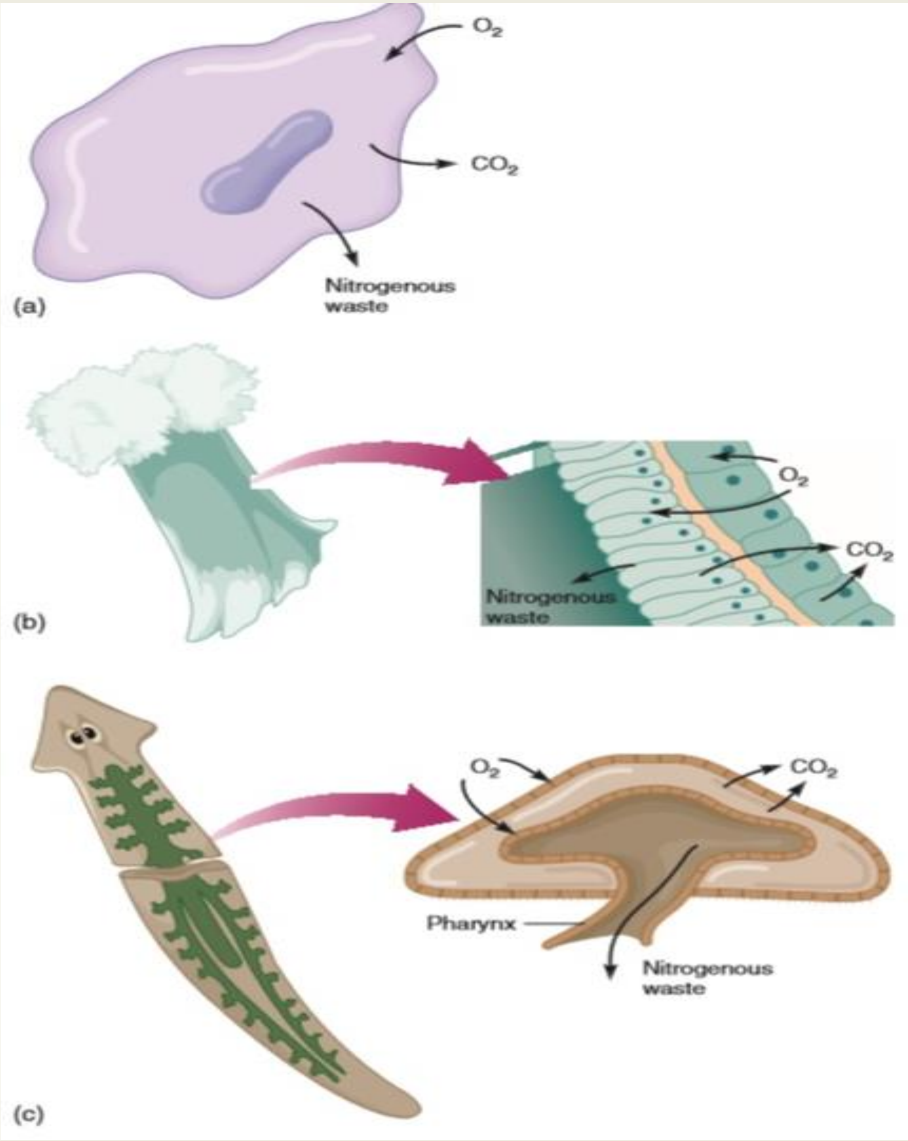


Fig: Invertebrate Respiration: Diffusion through Body Surfaces

INVERTEBRATE RESPIRATORY SYSTEMS

- Most aquatic invertebrates carry out gas exchange with gills.
- Other aquatic invertebrates have their gas exchange structures in more restricted areas i.e., parapodia in marine and annelid worms.
- tracheal systems consisting of highly branched chitin-lined tubes called tracheae. Tracheae open to the outside of the body through spiracles, which usually have some kind of closure device to prevent excessive water loss.
- Arachnids possess tracheae, book lungs, or both.
- In molluscan subclass Pulmonata—the land snails and slugs gas exchange structure is a pulmonate lung that opens to the outside via a pore called a pneumostome.

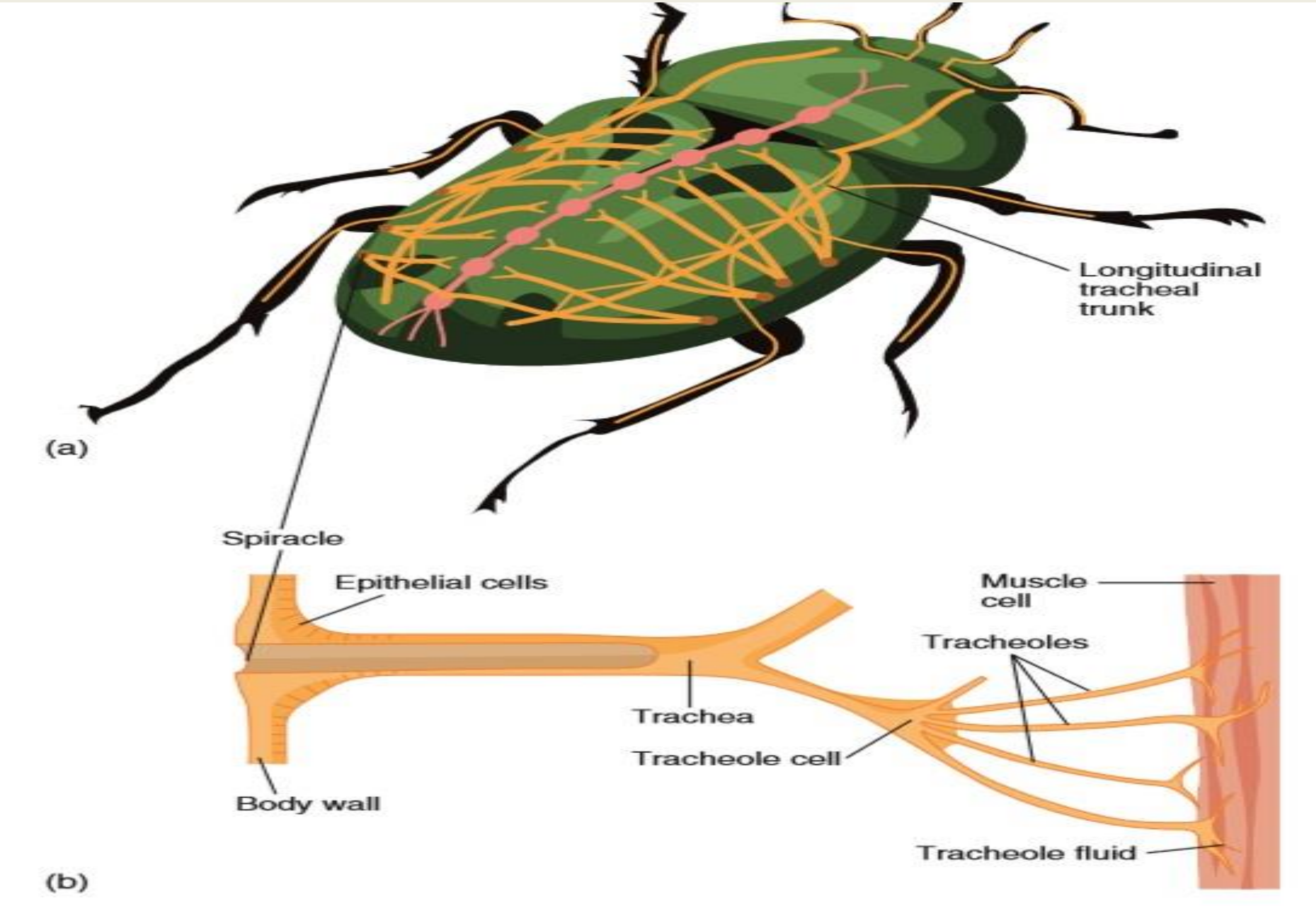


Fig: Invertebrate Respiration: A Tracheal System. (a) Tracheal system of an insect, showing the major tracheal trunks. (b) Tracheoles end at cells, and the terminal portions of tracheoles are fluid filled. The fluid acts as a solvent for gases.

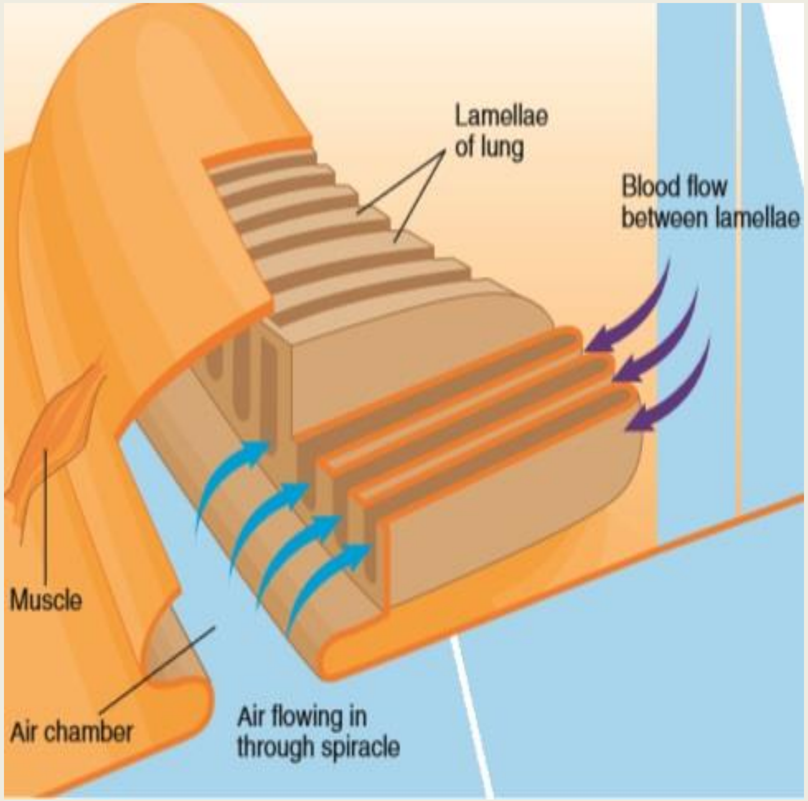


Fig: Invertebrate Respiration: A Book Lung. Structure of an arachnid (spider) book lung.

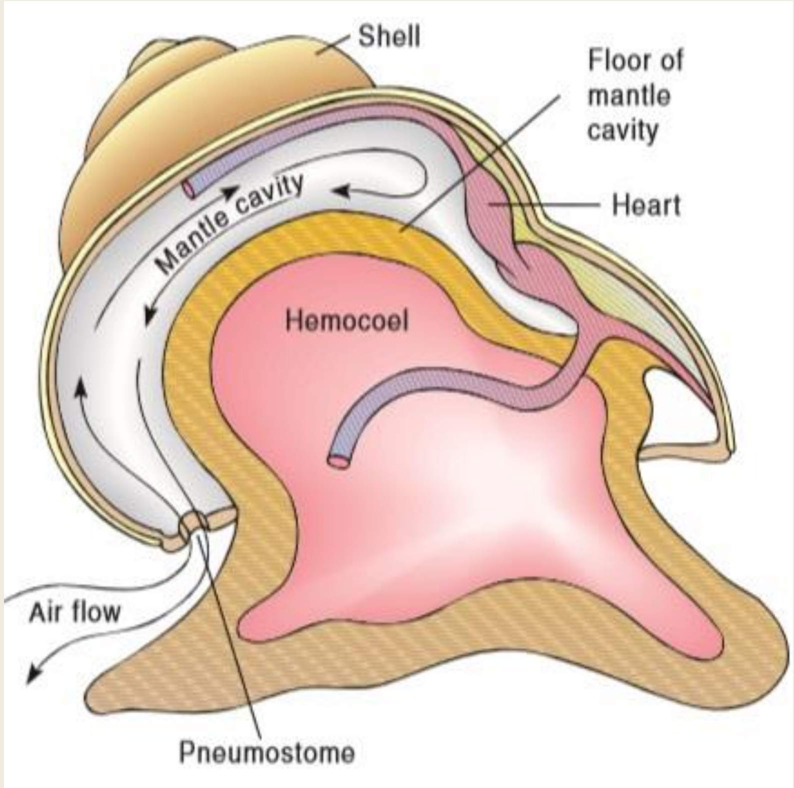


Fig: Invertebrate Respiration: The Pulmonate Lung. The mantle cavity of the pulmonate snail, *Lymnaea*

VERTEBRATE RESPIRATORY SYSTEMS

CUTANEOUS EXCHANGE

- Some vertebrates that have lungs or gills, such as some aquatic turtles, salamanders with lungs, snakes, fishes, and mammals, use cutaneous respiration or integumentary exchange to supplement gas exchange.

GILLS

- Gills are respiratory organs that have either a thin, moist, vascularized layer of epidermis to permit gas exchange across thin gill membranes, or a very thin layer of epidermis over highly vascularized dermis.
- The countercurrent exchange mechanism provides efficient gas exchange mechanism.

Fig: Vertebrate Respiration: External Gills. This axolotl (*Ambystoma tigrinum*) has elaborate external gills with a large surface for gas exchange with the water.

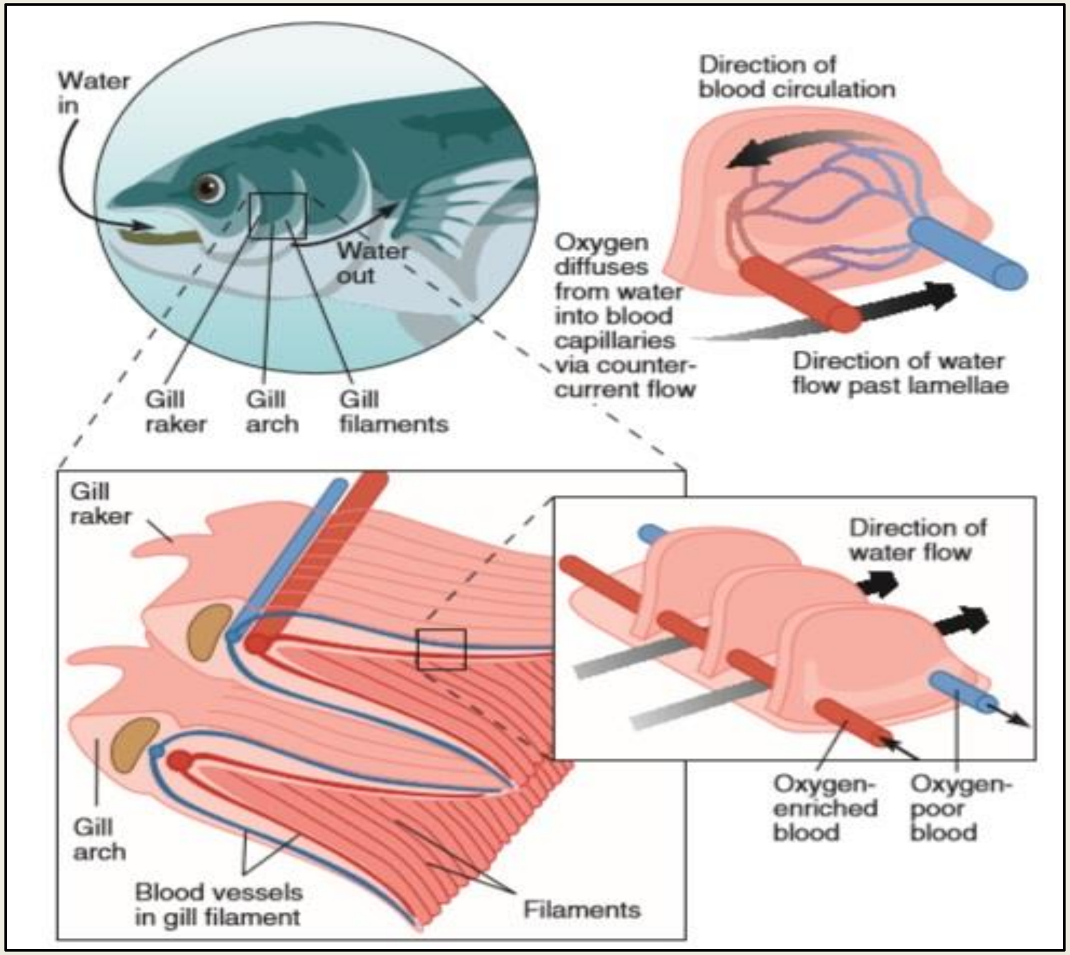


Fig: Vertebrate Respiration: Internal Gills. Removing the protective operculum exposes the feathery internal gills of this bony fish. Each side of the head has four gill arches, and each arch consists of many filaments. A filament houses capillaries within lamellae. Note that the direction of water flow opposes that of blood flow. This countercurrent flow allows the fish to extract the maximal amount of oxygen from the water

VERTEBRATE RESPIRATORY SYSTEMS

LUNGS

- A lung is an internal sac-shaped respiratory organ
- The evolution of the structurally complex lung paralleled the evolution of the larger body sizes and higher metabolic rates of endothermic vertebrates.

LUNGS VENTILATION

1. Air moves by bulk flow into and out of the lungs in the process called ventilation.
2. Oxygen and carbon dioxide diffuse across the respiratory surface of the lung tissue from pulmonary capillaries.
3. At systemic capillaries, oxygen and carbon dioxide diffuse between the blood and interstitial fluid in response to concentration gradients.
4. Oxygen and carbon dioxide diffuse between the interstitial fluid and body cells.

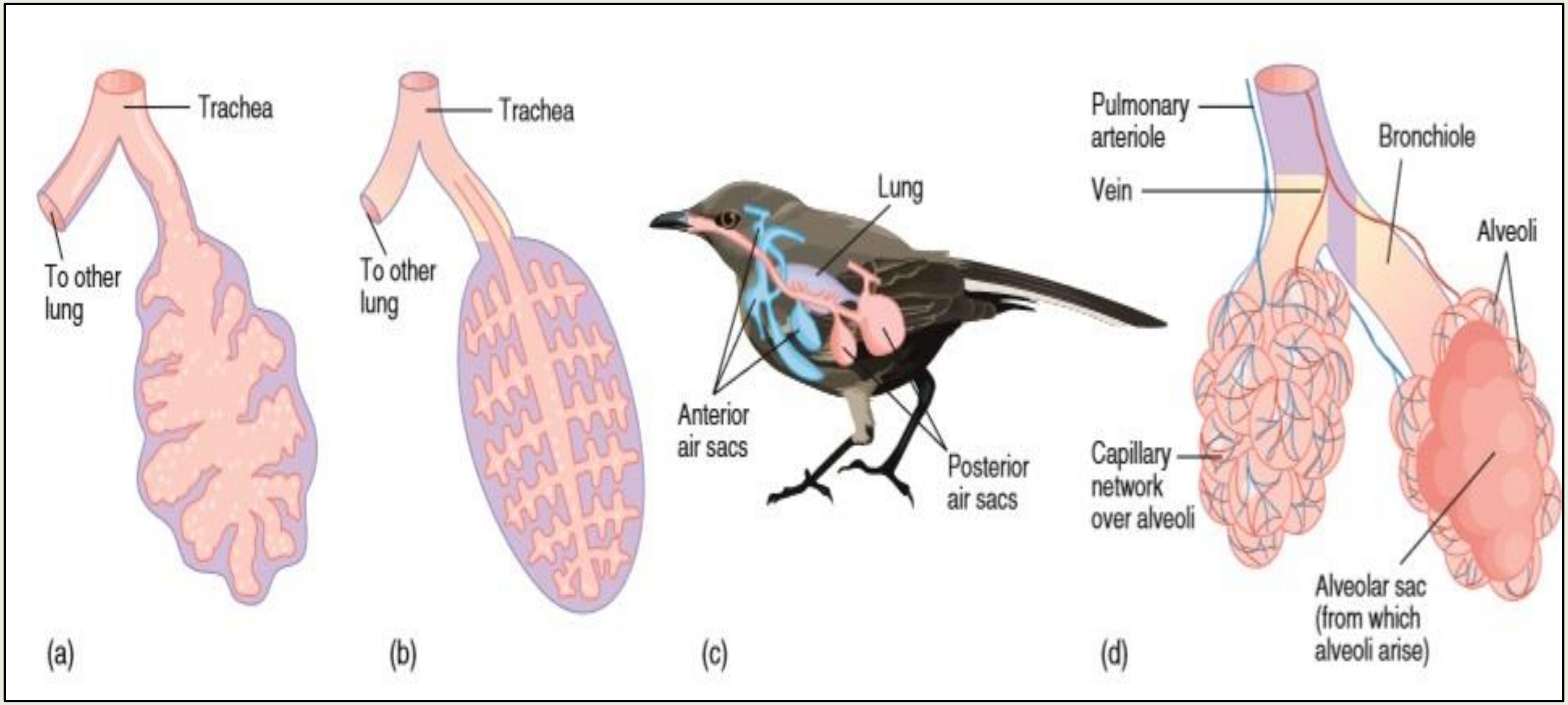


Fig: Vertebrate Respiration: Lungs. Evolution of the vertebrate lung, showing the increased surface area from (a) amphibians and (b) reptiles to (c) birds and (d) mammals. This evolution has paralleled the evolution of larger body size and higher metabolic rates.

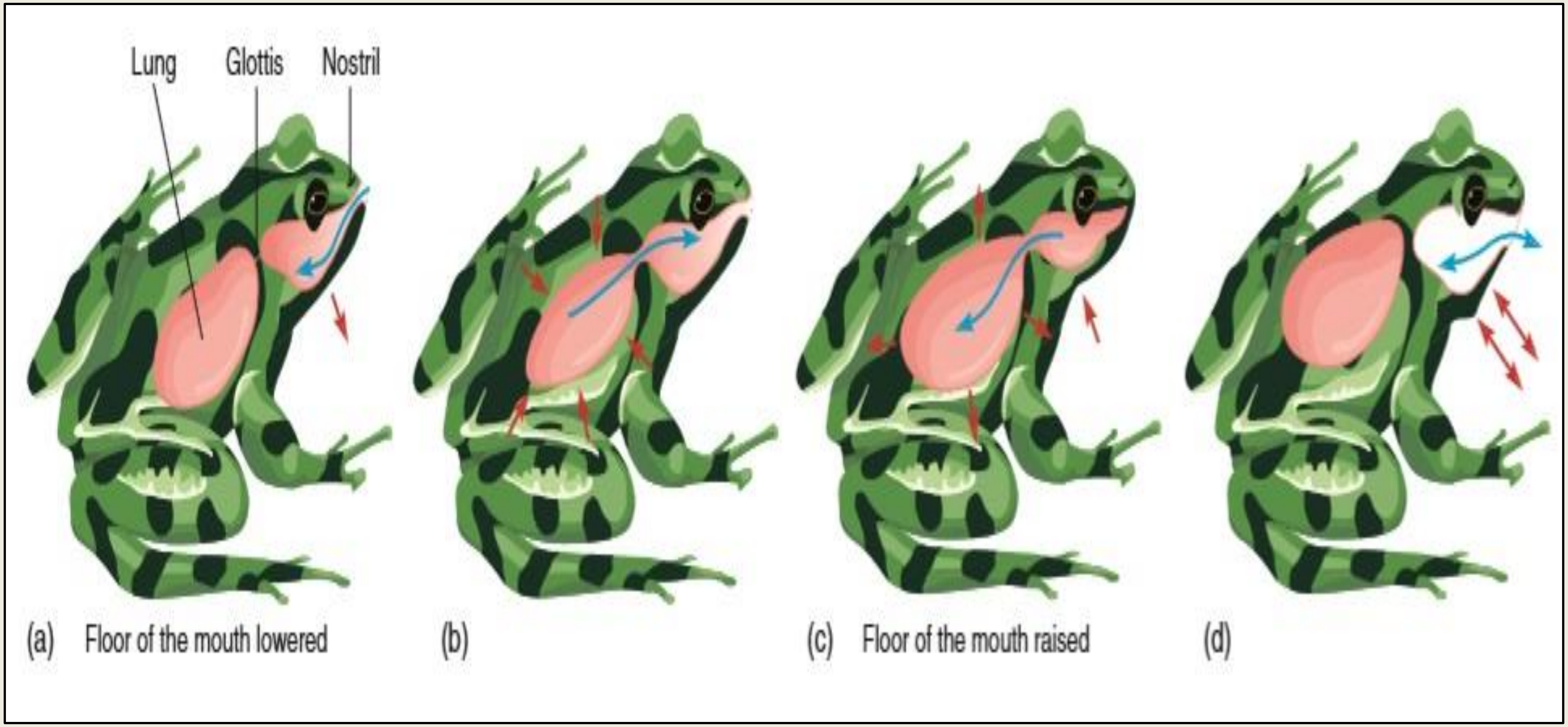


Fig: Ventilation in Amphibians. The positive pressure pumping mechanism in a frog (*Rana*). The breathing cycle has several stages. (a) Air is taken into the mouth and pharynx by lowering the floor of the mouth. Notice that the glottis is closed. (b) The glottis is then opened, and air is permitted to escape from the lungs, passing over the air just taken in. (c) With the nostrils and mouth firmly shut, the floor of the mouth is raised. This positive pressure forces air into the lungs. (d) With the glottis closed, fresh oxygenated air can again be brought into the mouth and pharynx. Some gas exchange occurs in the mouth cavity (buccopharyngeal respiration), and frogs may repeat this "mouth breathing'' movement several times before ventilating the lungs again. Red arrows indicate body wall movement, and blue arrows indicate air flow.

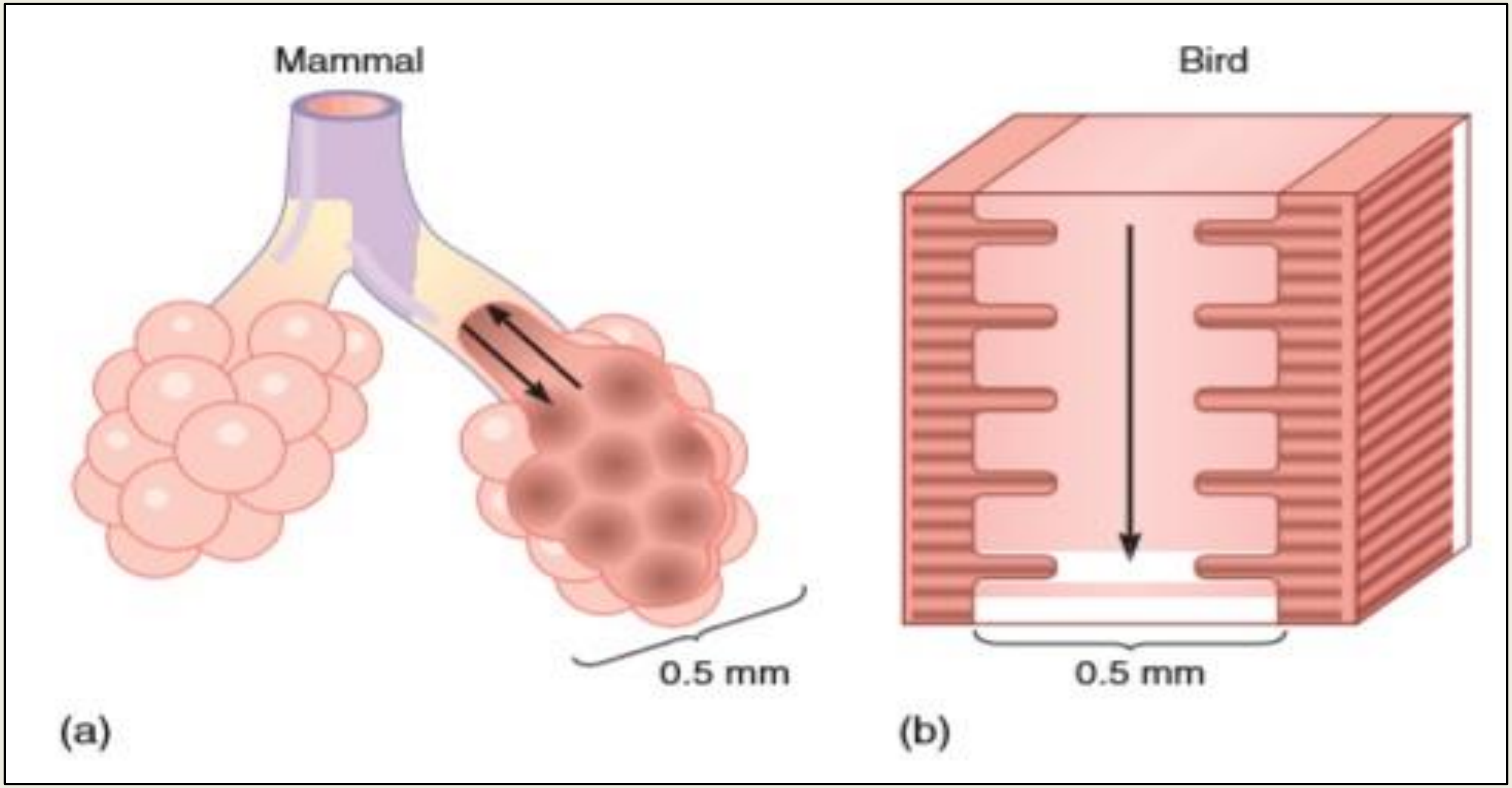
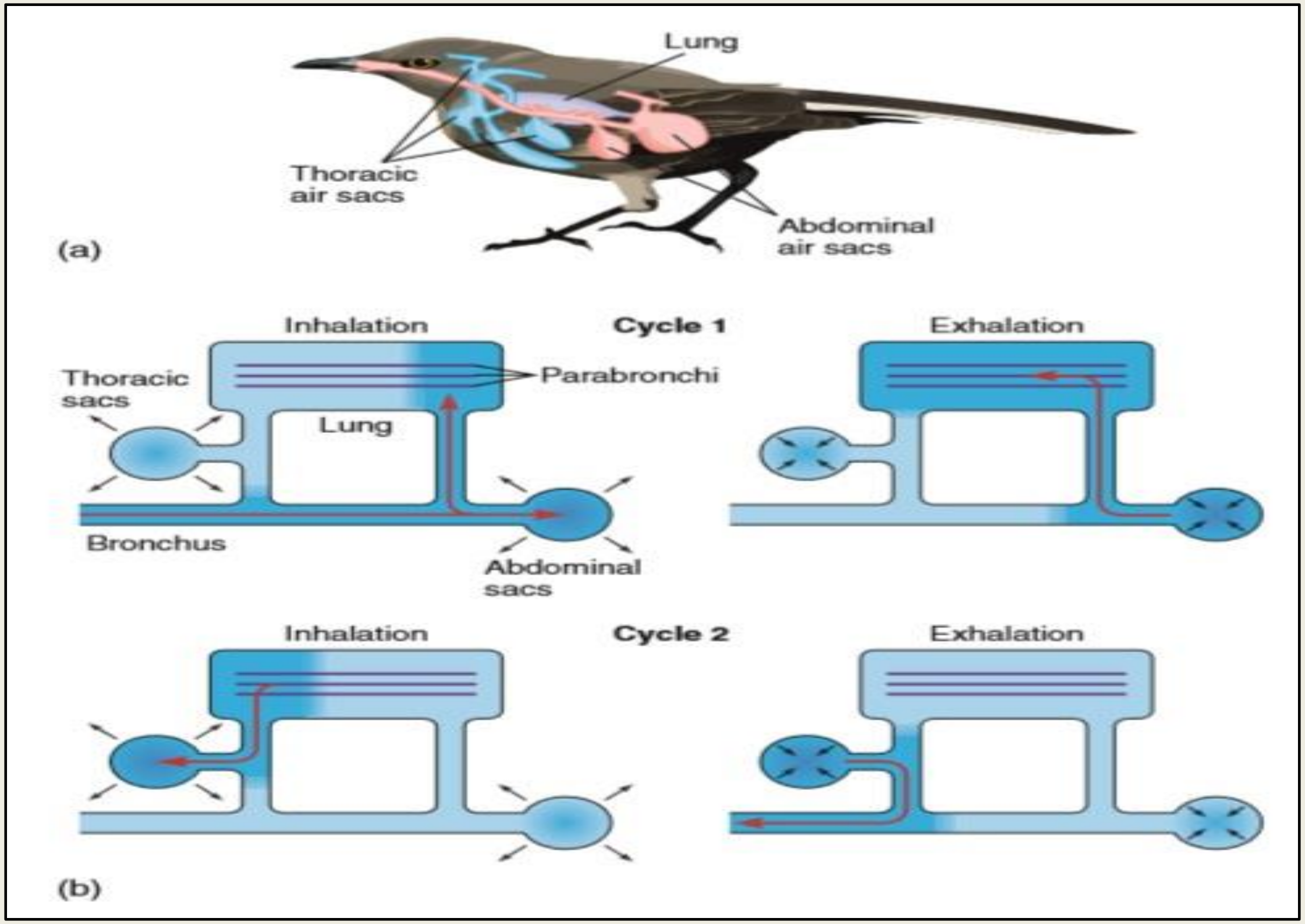


Fig: Gas Exchange Surfaces in Mammals and Birds. (a) The gas exchange surfaces in a mammal's lung are in saclike alveoli. Ventilation is by an ebb-and-flow mechanism (arrows), and the air inside the alveoli can never be completely replaced. (b) The smallest diameter passages in a bird lung are tubes that are open at both ends. Ventilation is by one-way flow (arrow), and complete replacement of air in the tubes is continuous.



Gas Exchange Mechanism in Birds. (a) Birds have a number of large air sacs. Some of them (abdominal) are posterior to the small pair of lungs, and others (thoracic) are anterior to the lungs. The main bronchus (air passageway) that runs through each lung has connections to air sacs, as well as to the lung. In (b), abdominal and thoracic air sacs are sketched as single functional units to clarify their relationship to the lung and bronchus. (b) Air flow through the bird respiratory system. The darker blue portion in each diagram represents the volume of a single inhalation and distinguishes it from the remainder of the air in the system. Two full breathing cycles are needed to move the volume of gas taken in during a single inhalation through the entire system and out of the body. This system is associated with one-way flow through the gas exchange surfaces in the lungs. Black arrows indicate expansion and contraction of air sacs. Red arrows indicate movement of air.

Air Passage consist of:

- ❑ **A conducting portion**
- ❑ **A respiratory portion**

Conducting portion

1) **Nasal or oral cavities**
2) **Nasopharynx and oropharynx**
3) **Larynx**
4) **Trachea**
5) **Paired pulmonary bronchi**

After each bronchus enters the lungs, it branches into smaller tubes called bronchioles, then even smaller tubes called terminal bronchioles, and finally, the respiratory bronchioles, which are part of the gas-exchange portion of the respiratory system.

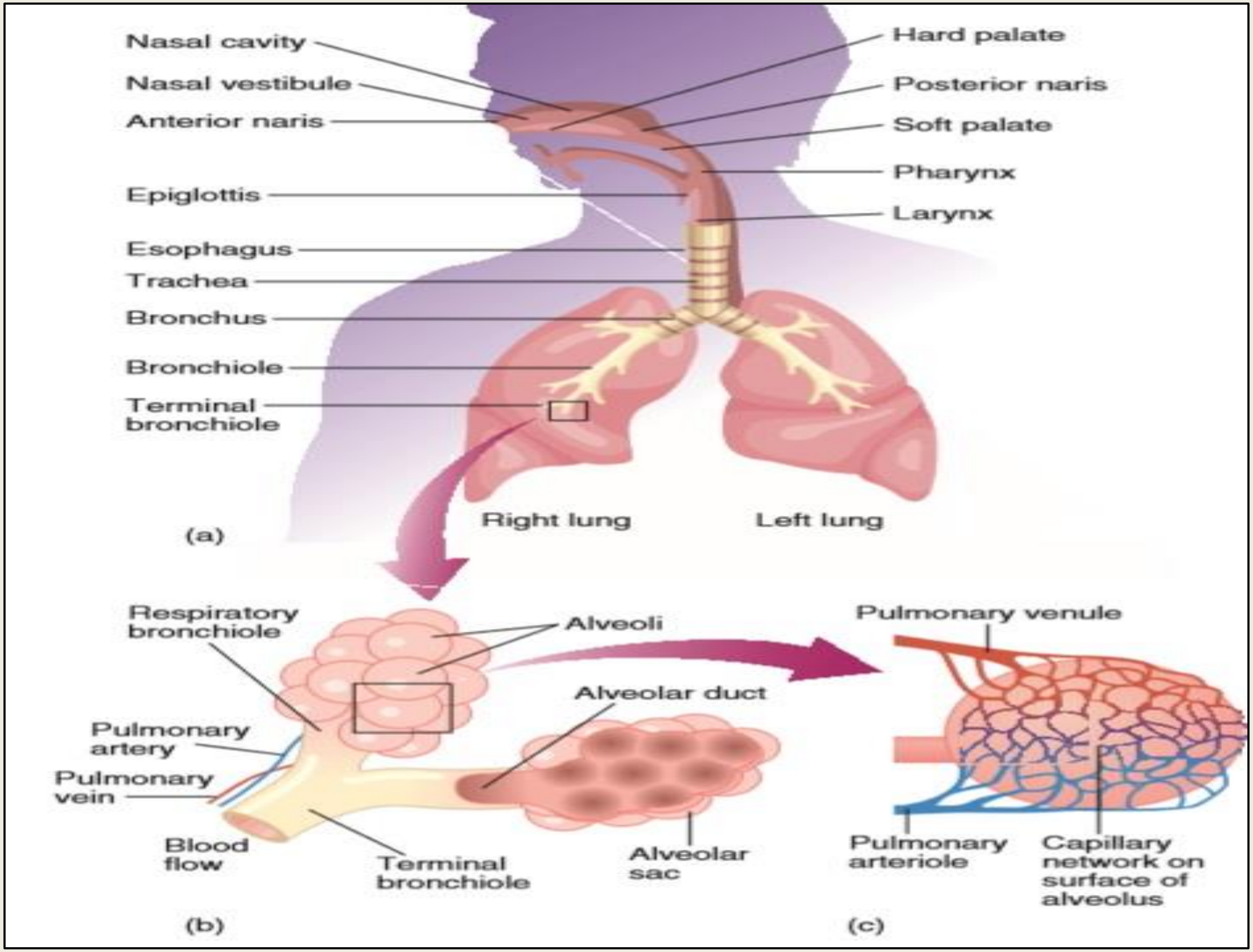


Fig: Organs of the Human Respiratory System. (a) Basic anatomy of the respiratory system. (b,c) The respiratory tubes end in minute alveoli, each of which is surrounded by an extensive capillary network.

Respiratory portion

- Small tubes called alveolar ducts connect the respiratory bronchioles to grapelike out pouchings called alveoli.
- The alveoli cluster to form an alveolar sac.
- Alveoli are the functional units of the lungs (gas exchange portion).
- Passive diffusion, driven by a partial pressure gradient, moves oxygen from the alveoli into the blood and moves carbon dioxide from the blood into the alveoli

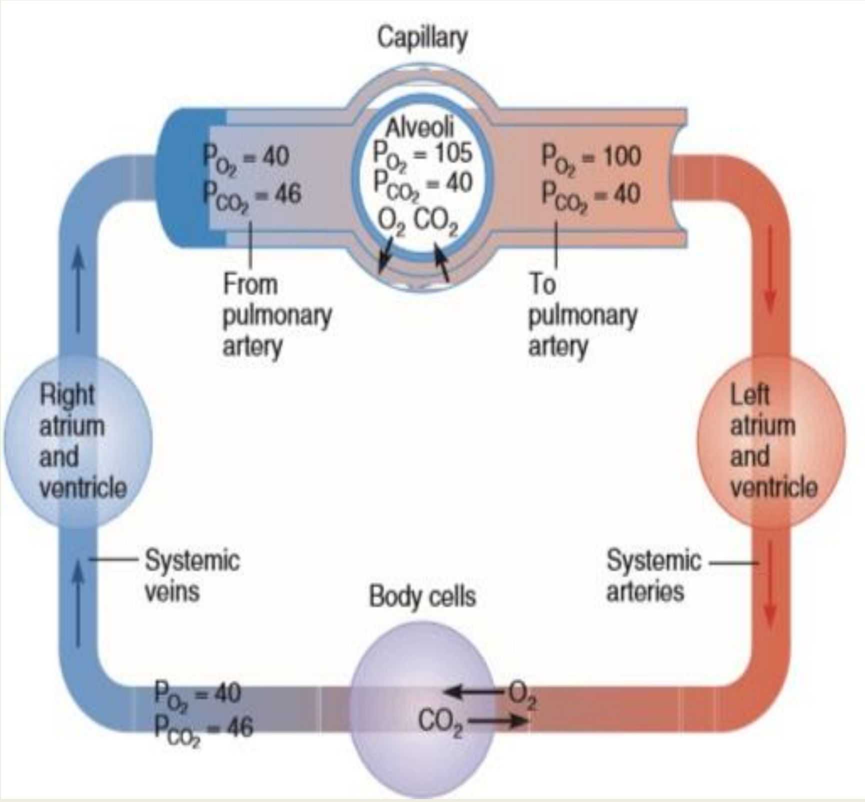


Fig: Gas Exchange between the Lungs and Tissues. Gases diffuse according to partial pressure (P) differences, as the numbers and arrows indicate.

Ventilation

Breathing (also called pulmonary ventilation) has two phases:

- **inhalation, the intake of air.**
- **exhalation, the outflow of air.**

The mechanism of inhalation operates in the following way:

1) **Several sets of muscles, the main ones being the diaphragm and intercostal muscles, contract. The intercostal muscles stretch from rib to rib, and when they contract, they pull the ribs closer together, enlarging the thoracic cavity.**
2) **The thoracic cavity further enlarges when the diaphragm contracts and flattens.**
3) **The increased size of the thoracic cavity causes pressure in the cavity to drop below the atmospheric pressure. Air rushes into the lungs, and the lungs inflate.**

During ordinary exhalation, air is expelled from the lungs in the following way:

1. **The intercostal muscles and the diaphragm relax, allowing the thoracic cavity to return to its original, smaller size and increasing the pressure in the thoracic cavity.**
2. **Abdominal muscles contract, pushing the abdominal organs against the diaphragm, further increasing the pressure within the thoracic cavity.**
3. **The action in step 2 causes the elastic lungs to contract and compress the air in the alveoli. With this compression, alveolar pressure becomes greater than atmospheric pressure, causing air to be expelled (exhaled) from the lungs.**

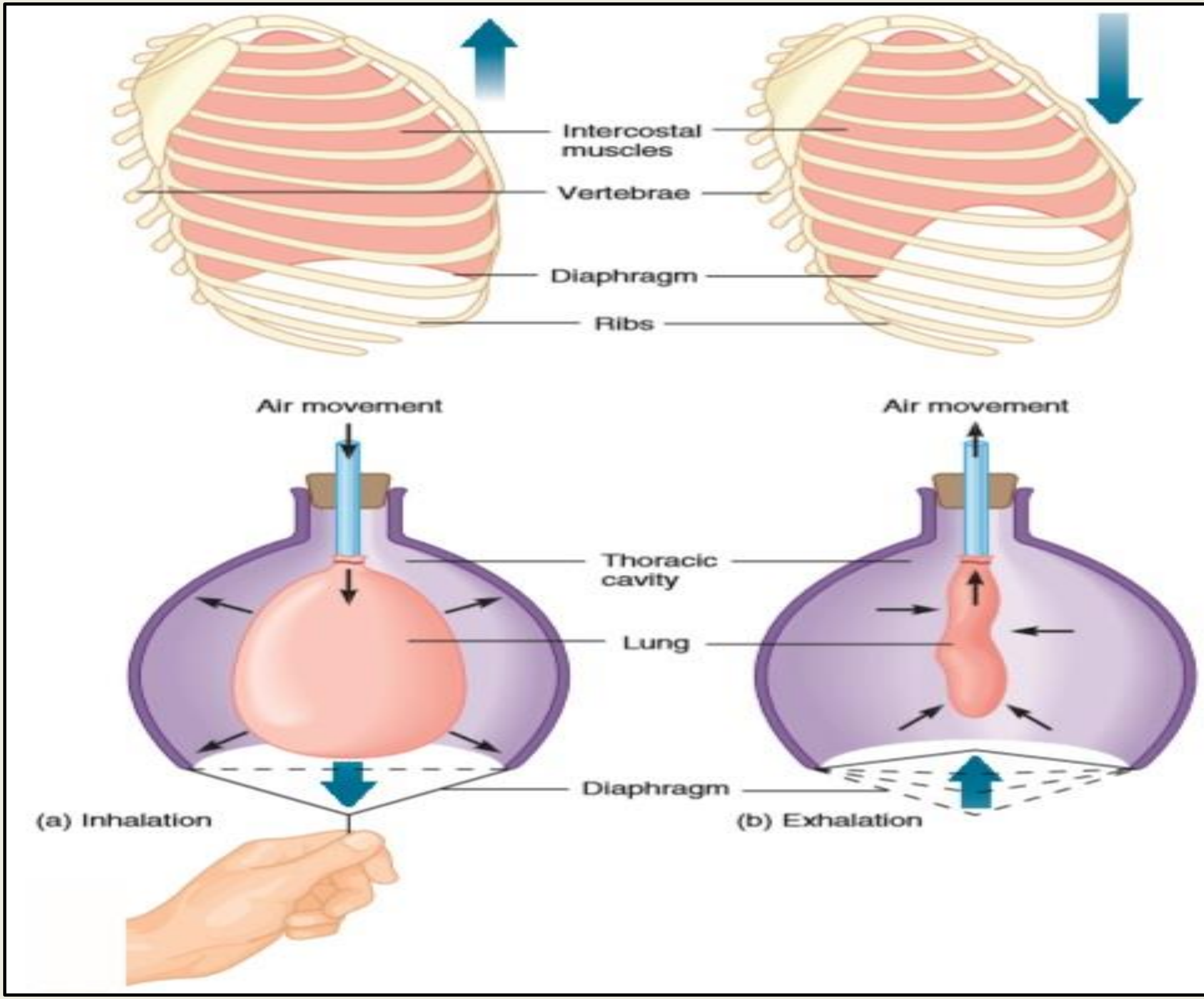


Fig: Ventilation of Human Lungs as an Example of Breathing in Mammals.

GAS TRANSPORT

- As animals became larger and acquired higher metabolic rates, simple diffusion became increasingly inadequate as a means of delivering oxygen to the tissues.
- More active animals have an increased demand for oxygen.
- Thus, fluid-borne respiratory pigments specialized for reversibly binding large quantities of oxygen evolved in most phyla,
- Respiratory pigments may also function in short-term oxygen storage.

Respiratory pigments

Respiratory pigments organic compounds that have either metallic copper or iron that binds oxygen.

Receptors

hemoglobin
- Contains iron as the oxygen binding metal
- Reddish pigment
- Hemoglobin may be carried within red blood cells

Hemocyanin
- Contains metallic copper
- Bluish color when oxygenated
- Always occurs dissolved in hemolymph

Hemerythrin
- Contains iron and is pink when oxygenate
- It is in nucleated cells

Chlorocruorin
- Contains iron
- Green when associated with low oxygen concentrations
- bright red when associated with high oxygen concentrations

Immune Response

Immunity refers to the general ability of an animal to resist harmful attack."

"Immunology is the study of immune system."

INVERTEBRATES

- Do not have immune system
- Have innate, internal defense mechanism

For example:

- granulocytes of Molluscs

VERTEBRATES

- Have immune system
- It is a large and specific complex of defensive elements, distributed throughout the body, that help the animal against attack.

ANTIGENS

Definition

"Foreign (non-self) substances (markers) to which lymphocytes respond are called antigens."

- Most antigens are large proteins or other complex molecules with a molecular weight generally greater than 10,000.

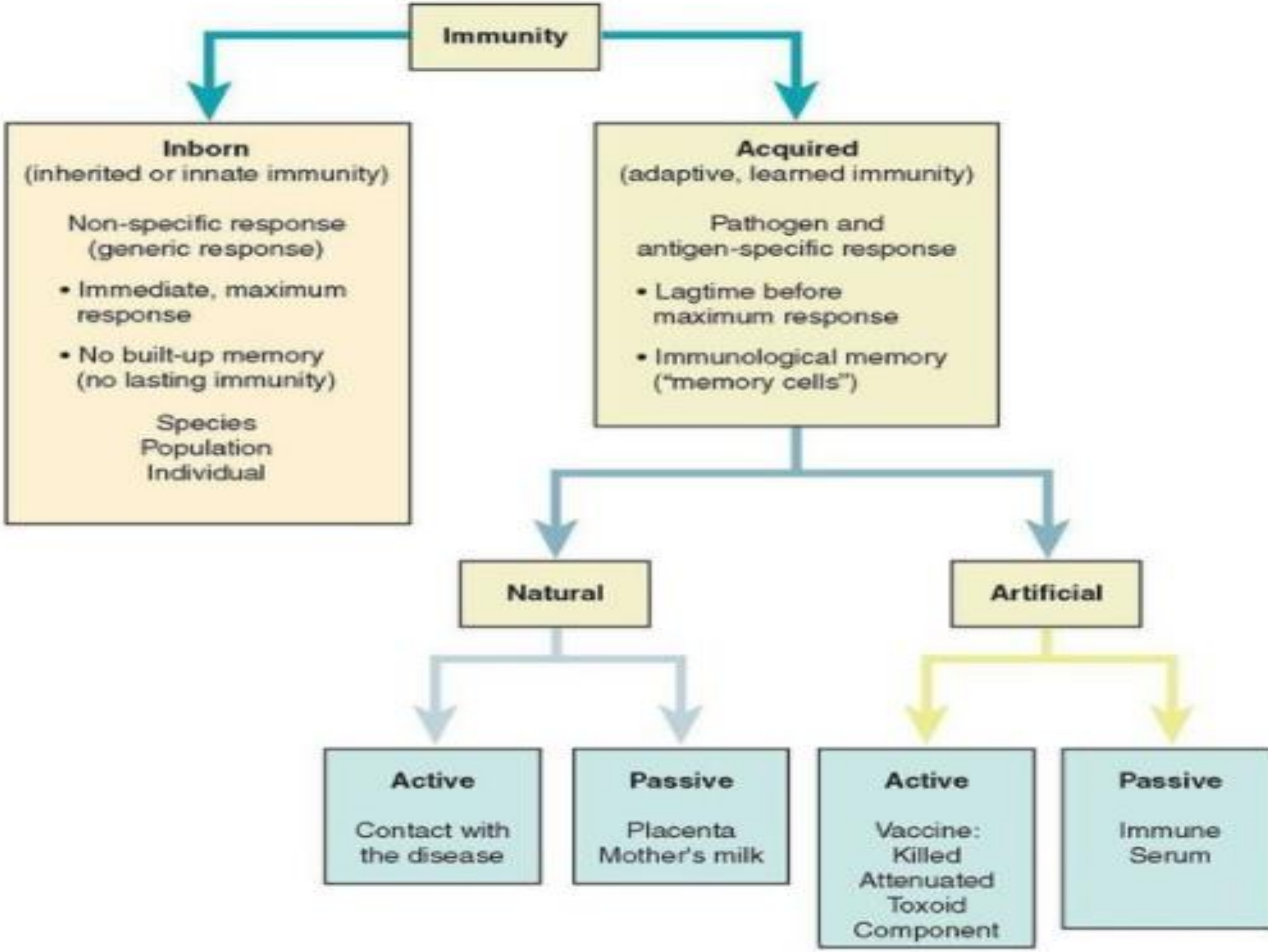
ANTIBODIES

Definition

Plasma cells manufacture antibodies (immunoglobulins), "a group of recognition glycoproteins present in the blood and tissue fluids of birds and mammals."

ANTIBODY STRUCTURE

- All antibody molecules have a basic Y structure.
- Composed of 4 chains of polypeptides connected by disulfide bonds.
- Arms of Y have binding sites for antigens.
- Tail of Y activate complement system.


Immunity
Inborn
(inherited or innate immunity)
Non-specific response
(generic response)
• Immediate, maximum response
• No built-up memory (no lasting immunity)
Species
Population
Individual
Acquired
(adaptive, learned immunity)
Pathogen and
antigen-specific response
• Lagtime before maximum response
• Immunological memory ("memory cells")
Natural
Artificial
Active
Contact with the disease
Passive
Placenta
Mother's milk
Active
Vaccine:
Killed
Attenuated
Toxoid
Component
Passive
Immune
Serum