a small but an important system.

Lymphatic system. It is found in chordates except cyclostomes and cartilaginous fishes. It includes lymph and lymph vessels. **Lymph** is a tissue fluid found amongst the body cells. It is blood plasma minus red blood corpuscles and some proteins. **Lymph capillaries** forming a network of thin blind-ending vessels, which collect lymph. **Lymph vessels** are thin-walled vessels formed by the union of blood capillaries. These empty into veins. **Lymph nodes** are found on lymph vessels in mammals. These form lymphocytes of blood used for body defence against diseases.

EVOLUTION OF HEART IN VERTEBRATES

The heart is an unpaired organ but its origin is bilateral. In an embryo the mesenchyme forms a group of **endocardial cells** below the pharynx. These cells become arranged to form a pair of thin **endothelial tubes**. The two endothelial tubes soon fuse to form a single **endocardial tube** lying longitudinally below the pharynx. The splanchnic mesoderm lying below the endoderm gets folded longitudinally around the endocardial tube. This two-layered tube will form the heart in which the splanchnic mesoderm thickens to form a **myocardium** or muscular wall of the heart and an outer thin **epicardium** or visceral pericardium. The endocardial tube becomes the lining of the heart known as **endocardium**. Folds of splanchnic mesoderm meet above to form a dorsal **mesocardium** which suspends the heart in the coelom. Soon a transverse septum is formed behind the heart which divides the coelom into two chambers, an anterior **pericardial cavity** enclosing the heart and a posterior **abdominal cavity**. The heart is a straight tube but it increases in length and becomes S-shaped because its ends are fixed. Appearance of valves, constriction, partitions in the heart, and differential thickenings of its walls form three or four chambers in the heart.

1. Single-chambered Heart

In *Amphioxus* (primitive chordate), a true heart is not found. A part of ventral aorta beneath the pharynx is muscular and contractile and acts as heart.

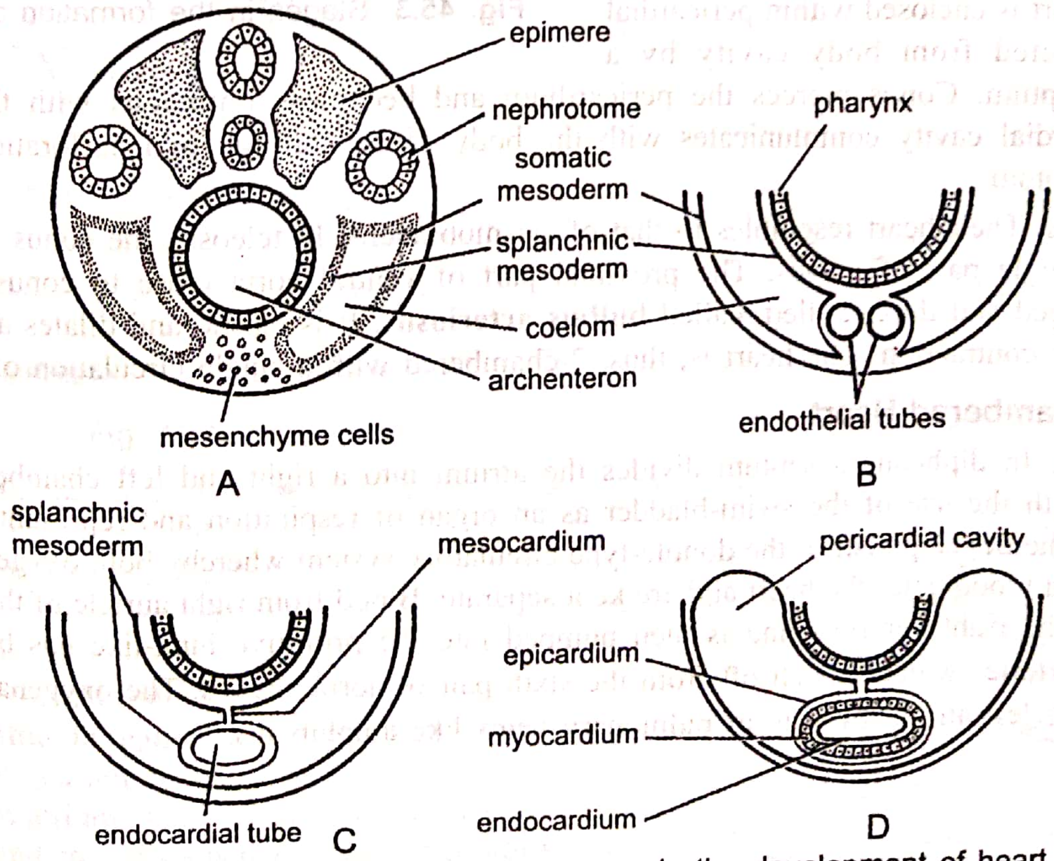

Fig. 45.2. T.S. of embryo showing stages in the development of heart.

2. Two-chambered Heart

In cyclostomes, there are four chambers arranged in a linear order : a thin-walled **sinus venosus**, a slightly muscular **atrium** (auricle), a muscular **ventricle** and a muscular **conus arteriosus** or **bulbus cordis**. It lies in the body cavity in which other visceral organs are also present. Out of four chambers, only atrium and ventricle correspond to the four chambers (paired atria and paired ventricles) of the higher vertebrates. In the evolution of heart many changes have taken place.

Elasmobranchs. Except Dipnoi, the circulatory system in fishes from cyclostomes to teleosts, only unoxygenated blood goes to the heart. From there it is pumped to the gills, aerated and then distributed to the body. The heart of cartilaginous dogfish is muscular and dorsoventrally bent S-shaped tube with four compartments in a linear series. They are sinus venosus and atrium for receiving venous blood, and a ventricle and conus arteriosus for pumping this blood. The heart is a **branchial venous heart**. The sinus venosus and conus arteriosus are **accessory chambers**. Atrium and ventricle are true chambers, thus, it is a 2-chambered heart. The sinus venosus opens anteriorly into atrium through sinu-atrial aperture guarded by a pair of valves. Atrium lies dorsal to ventricle and opens ventrally into ventricle through an atrio-ventricular aperture guarded by a pair of valves. The thick-walled, muscular ventricle opens into a narrow **conus arteriosus** containing valves in two series.

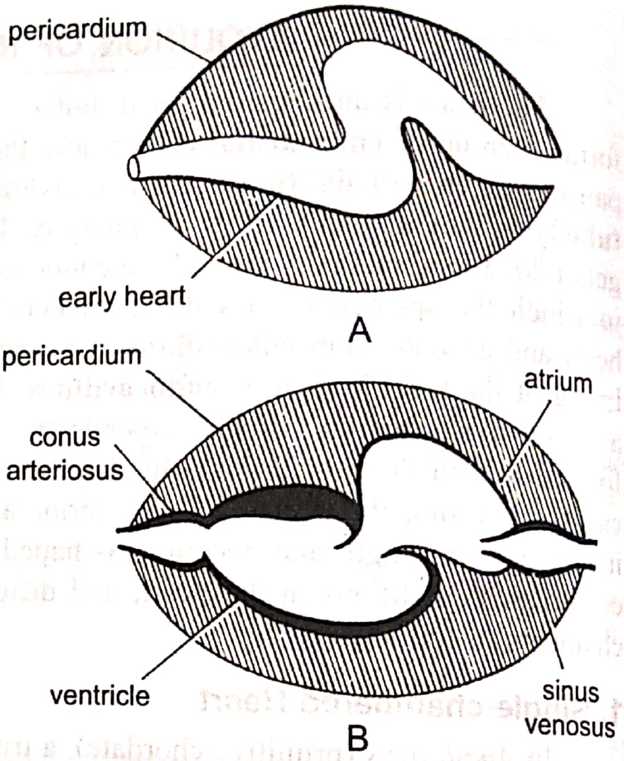

Fig. 45.3. Stages in the formation of heart.

The heart is enclosed within pericardial cavity separated from body cavity by a transverse septum. Conus pierces the pericardium and becomes continuous with the ventral aorta. Pericardial cavity communicates with the body cavity through two perforations in the transverse septum.

Teleosts. Their heart resembles to that of elasmobranchs. In teleosts, the conus is reduced and has a single pair of valves. The proximal part of ventral aorta close to conus becomes greatly enlarged and thick-walled, called **bulbus arteriosus**. It is elastic and dilates at the time of ventricular contraction. The heart is, thus, 2-chambered with a single circulation of blood.

3. Three-chambered Heart

Dipnoi. In diphoans a septum divides the atrium into a right and left chamber. This is correlated with the use of the swim-bladder as an organ of respiration and represents the first step toward the development of the double-type circulatory system whereby both oxygenated and unoxygenated blood enter the heart and are kept separate. Blood from right auricle of the lungfish passes into the right ventricle and is then pumped into the primitive lung-like gas bladder by pulmonary arteries which branch off from the sixth pair of aortic arches. The oxygenated blood returns to the left atrium by way of pulmonary veins like amphibians.

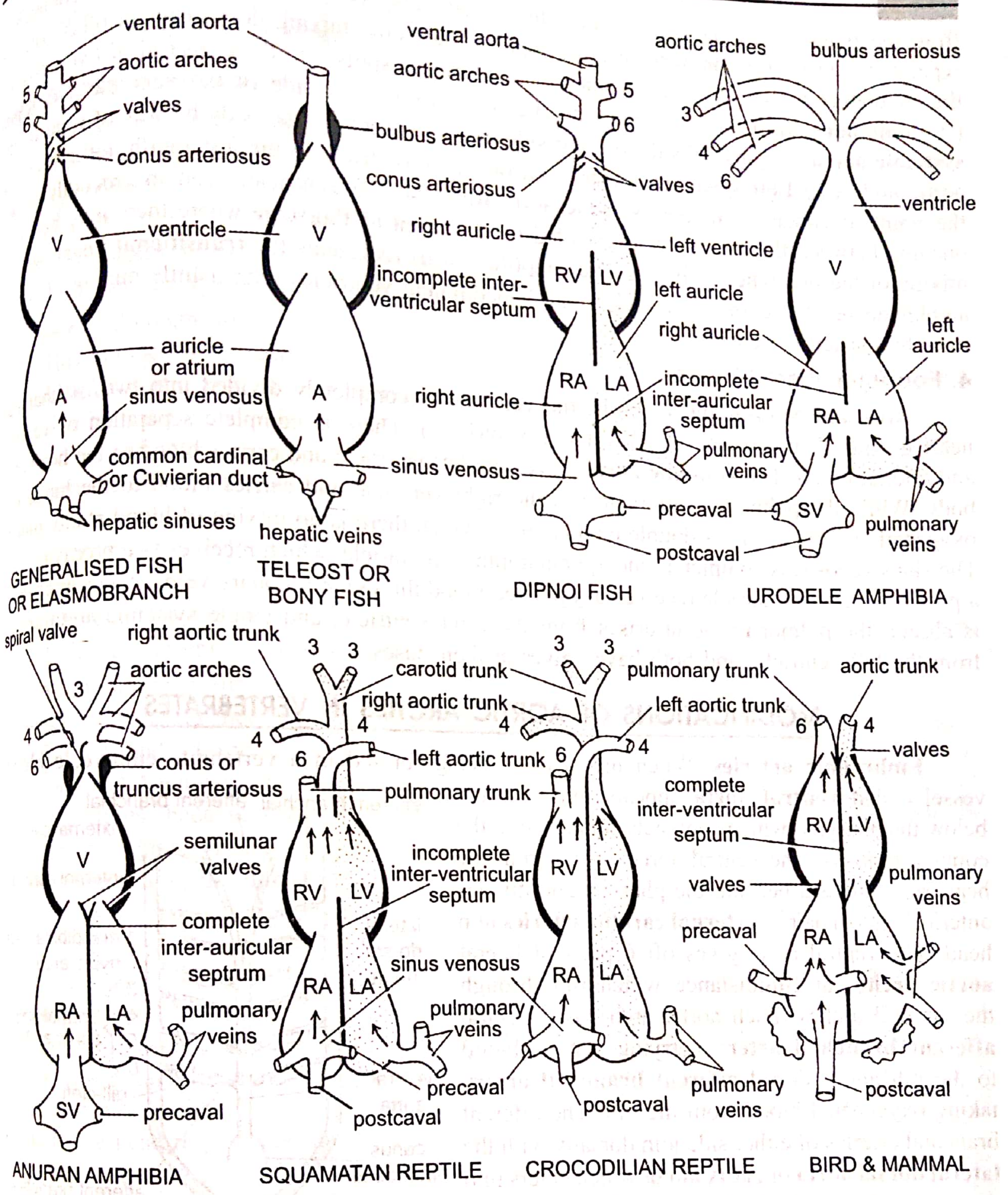

Fig. 45.4. Evolution of heart in different classes of vertebrates.

Amphibia. In amphibians, the dorsal atrium shifts anterior to ventricle. The sinus venosus opens into right atrium dorsally and not posteriorly. The atrium is completely divided into right and left chambers and has no foramen ovale in the inter-auricular septum, which remains open in dipnoans. Deep pockets develop in the ventricular cavity. The conus arteriosus divides into systemic and pulmonary vessels by a spiral valve. In lungless salamanders, the inter-atrial septum is incomplete and pulmonary veins are absent.

Reptilia. In reptiles, the heart is further advanced. The atrium is always completely separated into a right and left chamber, and in many forms the sinus venosus is incorporated into the wall of the right atrium. The ventricle is also partly divided by a septum in most reptiles, and in the alligators and crocodiles is completely two-chambered. This means that oxygenated blood coming from the lungs to the left side of the heart is essentially separted from the non-oxygenated blood from the body to the right side. Thus, in crocodilians, the two types of blood is completely separated, and nearly complete in other reptiles, but some mixing does occur in other parts of the circulatory system. The embryonic conus arteriosus splits into three instead of two vessels : (*i*) **Pulmonary arch** carrying blood to the lungs from right side of the ventricle. (*ii*) **Right systemic aorta** carrying blood from left side of the ventricle to the body by way of right fourth aortic arch. (*iii*) **Left systemic** comes from the right ventricle to the left fourth aortic arch. At the point of contact with the systemic aorta from the left ventricle, even in crocodilians, an opening between the two is present, called the **foramen of Panizzae** where there may be some mixing of the two types of blood. Thus, reptilian heart represents the **transitional heart** against amphibian heart–2 complete auricles and 2 incomplete ventricles with a little mixing of blood in right and left systemics.

4. Four-chambered Heart

Aves and Mammalia. In birds, the ventricle is completely divided into two, so that the heart is four chambered (2 auricles and 2 ventricles). There is complete separation of venous and arterial blood. The **systemic aorta** leaves the left ventricle and carries blood to the head and body. While the pulmonary artery leaves the right ventricle and carries blood to the lungs for oxygenation. Thus, there is double circulation in which there is no mixing of blood at any place. The sinus venosus is completely incorporated into right auricle, which receives two precavals and a postcaval. The left auricle receives oxygenated blood through pulmonary veins, conus arteriosus is absent, the pulmonary aorta arises from the right ventricle, and single systemic aorta arises from the left ventricle, and both have valves at their bases.

MODIFICATIONS OF AORTIC ARCHES IN VERTEBRATES

Embryonic arteries. When the heart is being formed in a vertebrate embryo, a blood vessel called **ventral aorta** appears mid-ventrally below the pharynx, which soon gets connected to the conus arteriosus. The ventral aorta arising from the heart runs forward beneath the pharynx and divides anteriorly into a pair of **external carotid arteries** into head. The ventral aorta gives off 6 pairs of lateral **aortic arches** at equidistance which run through the visceral arches. Each aortic arch has a ventral **afferent branchial artery** carrying venous blood to the gill and a dorsal **efferent branchial artery** taking oxygeneted blood from the gill. The efferent branchial arteries of either side join dorsally with the **lateral dorsal aorta** or **radix aorta** which enters into the head as **internal carotid artery**. The first aortic arch is **a mandibular aortic arch**, the second is a **hyoid aortic arch**, the remaining ones are called third, fourth, fifth and sixth aortic arches. The lateral dossal aorta fuse behind the pharynx to form a **dorsal aorta** which is continued mid-dorsally into the tail as a **caudal artery**. From the dorsal aorta paired and unpaired arteries arise which supply various organs of the body. In an embryo with a yolk sac, a pair of **vitelline ariteries** arise from the dorsal aorta and supply the yolk sac. In embryos of amniotes a pair of **umbilical** or **allantoic arteries** arise from the

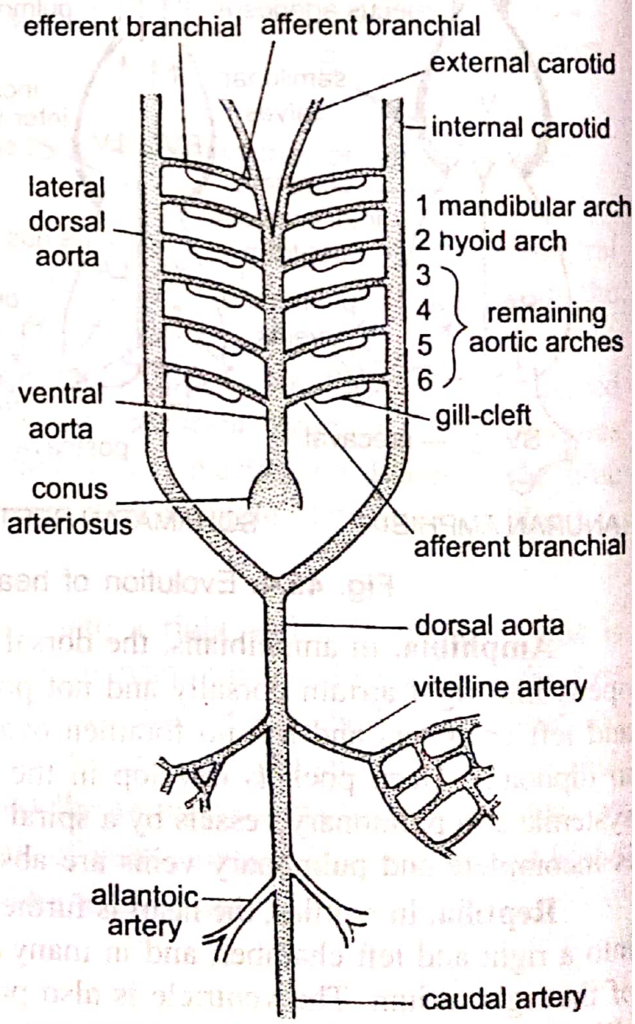

Fig. 45.5. Embryonic aortic arches and arteries.

dorsal aorta supplying blood to the allantois. In an adult the vitelline arteries fuse to form the main mesenteric artery, the major part of the allantoic arteries is lost, but their remnants form hypogastric or internal iliac arteries.

Aortic Arches in Vertebrates

In various adult vertebrates, the arterial system appears to be different, but they are built on the same basic fundamental plan. The difference is due to increasing complexity of heart due to a change in respiration from gills to lungs. There is a progressive reduction in the number of aortic arches in the vertebrate series.

Cyclostomata. In *Petromyzon*, there are 7 pairs of aortic arches. In other cyclostomes these vary from 6 pairs in *Myxine* and 15 pairs in *Eptatretus*.

Pisces. Although six is considered to have been the basic number of aortic arches for fishes. This number is reduced to five even in sharks and rays with the loss of the first pair, the mandibular aortic arch or it is represented by an efferent pseudobranchial artery. In most bony fishes both the mandibular (*i*) and hyoid (*ii*) aortic arches disappear or are much reduced. In *Polypterus* and Dipnoi (lung-fishes), gills are not well developed. So the **pulmonary artery** arises from the efferent part of 6th arch on either side which supplies blood to the air bladder or lung. In elasmobranchs and Dipnoi each arch has one afferent and two efferent branchial arteries (formed by splitting) in each gill. In bony fishes each gill has one afferent and one efferent artery.

In tetrapoda aortic arches do not break up into afferent and efferent parts because true internal gills are absent. In all tetrapoda the first and second arches disappear.

Amphibia. Here the aortic arches show modification due to loss of gills and appearance of the lungs. In **urodeles** there are external gills present as respiratory organs in addition to lungs. The III, IV, V and VI aortic arches are present, though the fifth pair is much reduced in *Siren*, *Amphiuma* and *Necturus*. The aortic arches are not broken in the external gills into afferent and efferent portions, because branches arising from IV, V, and VI aortic arches form capillaries in the external gills. The lateral dorsal aortae between the III and IV aortic arches persist as a vascular connection, the **ductus caroticus**. The VI aortic arch forms the pulmo-cutaneous arch or artery on either side taking blood to the lung and skin. It also retains a connection with the lateral dorsal aorta known as a **ductus arteriosus** (duct of Botalli).

In the larva of anuran (frog tadpole), arrangement of aortic arches are like an adult urodele due to presence of gills. At metamorphosis, with the loss of gills, I, II, and V aortic arches disappear completely, only the IIIrd, IVth and VIth aortic arches are present. The lateral dorsal aorta between the third and fourth aortic arches (ductus caroticus) also disappears. Thus, the third aortic arch along with a part of the ventral aorta becomes the carotid arch carrying oxygenated blood to the head region. The fourth aortic arch along its lateral dorsal aorta forms the systemic arch. The sixth aortic arch becomes the pulmocutaneous arch supplying venous blood to lungs and skin. The ductus arteriosus disappears during metamorphosis. Thus, adult anurans have only III, IV and VI aortic arches. These are also retained by amniotes.

Reptilia. In reptiles, the gills are fully replaced by lungs. Only III, IV and VI aortic arches are present. With the partial separation of the ventricle into two parts, the distal portion of the conus arteriosus and the entire ventral aorta are split into three vessels, *i.e.*, two aortic or systemic and one pulmonary. **Right systemic arch** (IV) arise from the left ventricle carrying oxygenated blood to the carotid arch (III). The **left systemic** (IV) and pulmonary aortae (VI) take their origin from the right ventricle. The left systemic carries deoxygenated or mixed blood to the body through dorsal aorta. While the pulmonary artery takes deoxygenated blood to the lungs. The ductus caroticus disappears, but it persists in snakes and some lizards (*Uromastix*). The ductus arteriosus disappears in most reptiles though it persists in a reduced form in *Sphenodon* and some turtles. Due to mixing of blood, reptiles are cold blooded animals like fishes and amphibians.

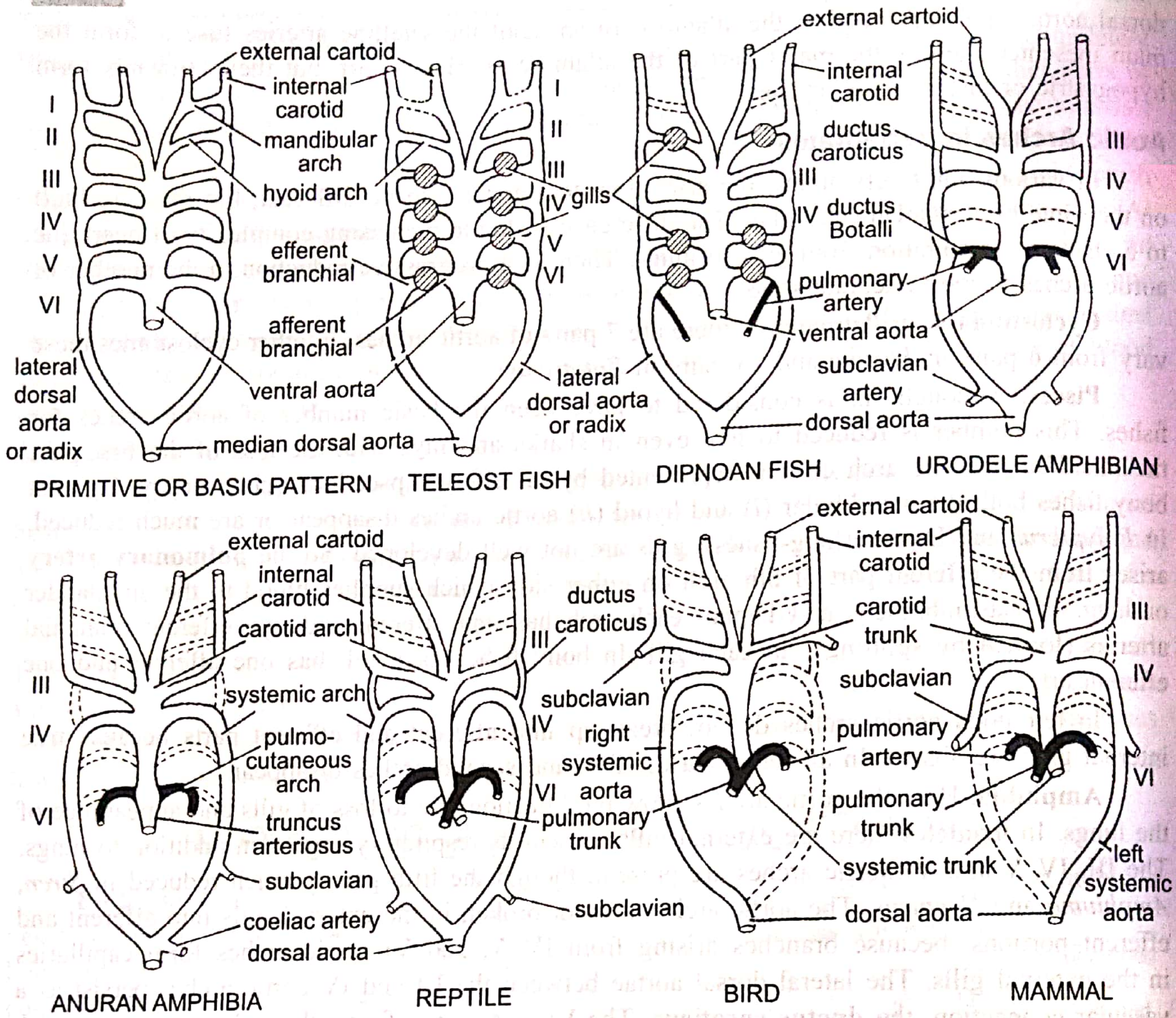

Fig. 45.6. Modification of aortic arches in representative vertebrates.

Aves. In birds, the III, IV and VI aortic arches are present. They follow the general pattern of reptiles with some differences. With the complete division of the ventricle into two parts, the conus arteriosus and ventral aorta have split to form two vessels, **systemic aorta** arising from the left ventricle and a **pulmonary aorta** from the right ventricle. **Third aortic arch** with remnants of lateral and ventral aortae form the carotids which arise from systemic aorta. **Fourth aortic arch** forms the **systemic aorta** on the right side only. It unites with the lateral aorta of its own side and forms the dorsal aorta. Part of the fourth aortic arch of the left side forms the **left subclavian artery**, the rest along with its lateral dorsal aorta disappears. The **sixth aortic arch** forms the pulmonary aorta. **Ductus caroticus** and **ductus arteriosus** disappear.

Mammalia. In mammals also the III, IV and VI aoric arches persist. The ventricle is divided completely into two parts. The conus arteriosus and ventral aorta split to form two vessels : (*i*) a **systemic aorta** arising from the left ventricle, and (*ii*) a **pulmonary aorta** from the right ventricle. **Third aortic arch** with remnants of lateral and ventral aortae forms the carotid arch. **Fourth aortic arch** forms the systemic aorta on the left side only, while on the right side its proximal portion forms an **innominate** and **right subclavian artery**, the rest along with its lateral dorsal aorta disappears. **Sixth aortic arch** forms the pulmonary aorta. The ductus arteriosus degenerates but it persists in some until hatching or birth in a reduced form on the left side as a thin **ligamentum arteriosum**.