Evolution of heart and aortic arches in vertebrates

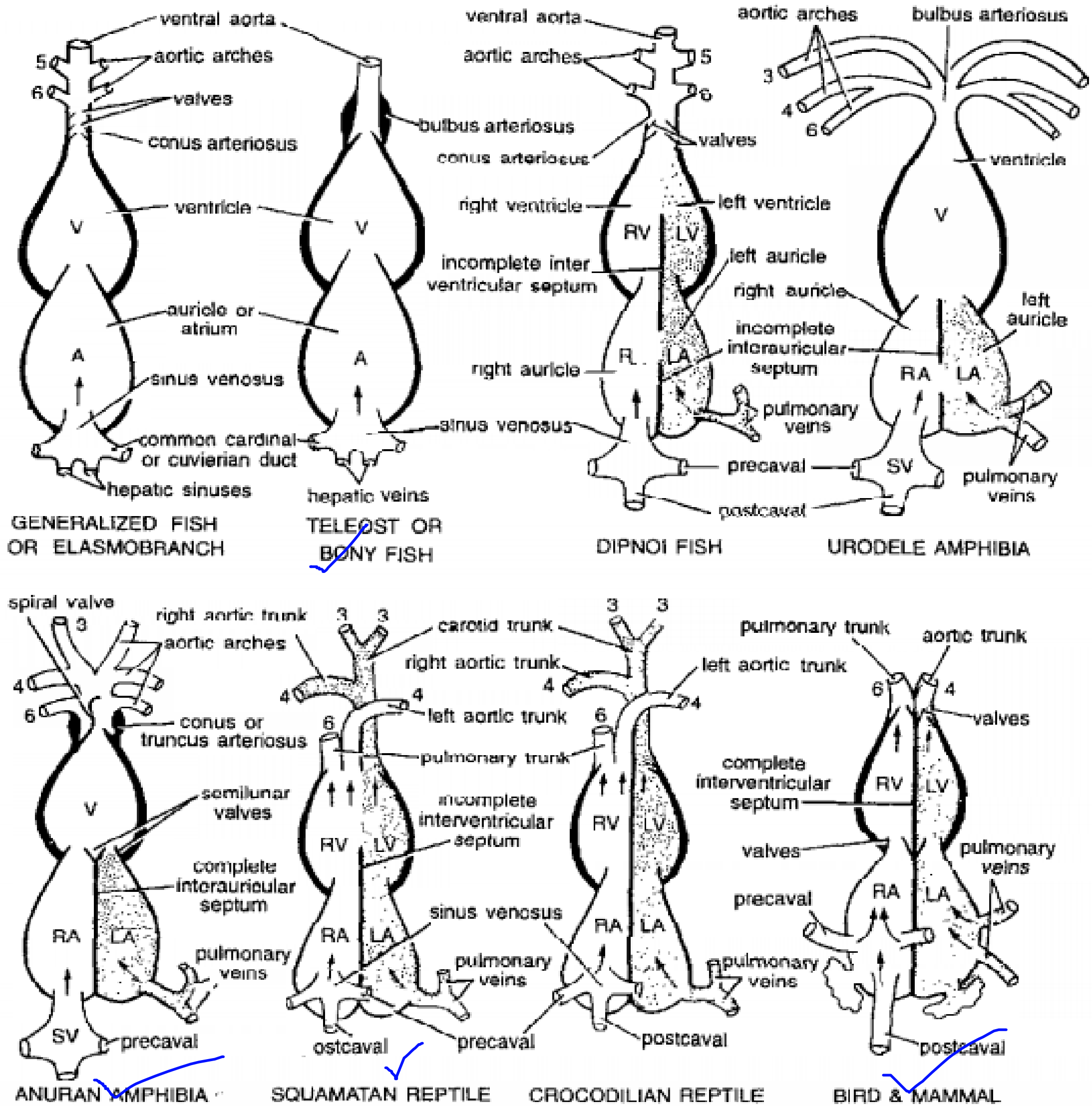

Fig. 2. Successive modifications of heart during evolution in different classes of vertebrates. 1—6 represent aortic arches. Shaded chambers contain mainly oxygenated blood. LA—left auricle, LV—left ventricle. RA—right auricle. RV—right ventricle. SV—sinus venosus.

Modifications of Aortic Arches in Vertebrates

Basic embryonic plan. In a typical vertebrates embryo, the major arterial channels include a *ventral aorta*, a *dorsal aorta* and usually 6 pairs of *aortic arches* connecting ventral aorta with the dorsal aorta (Fig. 3). Blood leaves the heart through *ventral aorta* which runs forward,

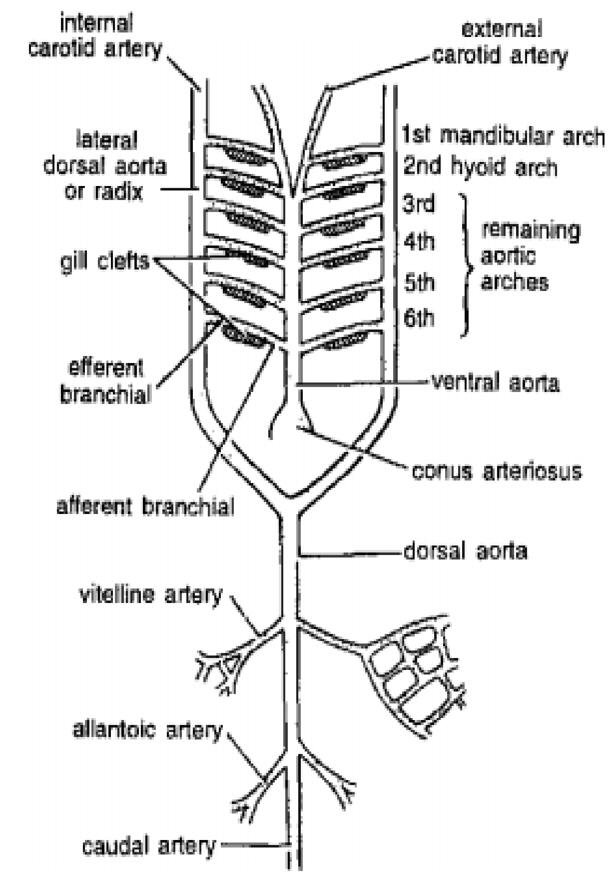

Fig. 3. Basic pattern of chief arterial channels of a typical vertebrate embryo.

midventrally beneath the pharynx and branches anteriorly into a pair of *external carotid arteries* into head. Ventral aorta gives off, at intervals, 6 pairs of *aortic arches* running through the visceral arches. Each *aortic* arch consists of a ventral *afferent branchial artery* carrying venous blood to capillaries in a gill, and a dorsal *efferent branchial artery* taking arterial blood from the gill. All the efferent branchial arteries of the same side dorsally join a *lateral dorsal aorta* or *radix* which is extended into head as the *internal carotid artery*. The two lateral dorsal aortae unite just behind the pharynx to form a single median *dorsal aorta* which continues behind into tail region as *caudal artery*. Branches from these main arterial channels supply all parts of the vertebrate body.

Although arterial system of different adult vertebrates shows major differences, but it is actually built according to the same basic architectural plan as seen in the vertebrate embryo (Fig. 4). The differences are due to increasing complexity of heart on account of a shift from gill respiration to lung respirat'on. ‾e mo¨¨cat'ons mainly concern the aortic arches which undergo a progressive reduction in number from lower to higher vertebrates.

Primitive vertebrates. In *Branchiostoma* (amphioxus), nearly 60 pairs of aortic arches are present, connecting the ventral and dorsal aortae. In *Petromyzon*, 7 pairs of aortic arches are found. In other cyclostomes the number varies from 6 *(Myxine)* to 15 pairs *(Eptatretus)*.

Fishes. The primitive elasmobranch *(Heptanchus)* has 7 pairs of aortic arches. Most of the fish embryos present primitive plan with 6 or more pairs of aortic arches, each passing through a gill. But, in adult condition, the number is reduced to 4 or 5. In most sharks (elasmobranchs), only 5 pairs (II, III, IV, V, and VI) are functional. The first gill slit forms the spiracle which is non-functional as a gill. Accordingly the first arch (mandibular) is absent or represented by an e_ere t p e_ _ an_ ial a _ry. _n m_st t_l__sts _r bony fishes, I and II arches tend to disappear, so that only 4 pairs (III, IV, V and VI) remain functional. In *Polypterus* and lungfishes (Dipnoi), gills are poorly developed, so that a *pulmonary artery* arises from the efferent part of the VI arch on each side and supplies blood to the developing air bladder or lung. In *Protopterus*, the III and IV embryonic arches are uninterrupted by gill capillaries.

In elasmobranchs and lungfishes, each arch forms one afferent and two efferent arteries (by splitting) in each gill. In teleosts or bony fishes, each gill has one afferent and one efferent artery. In tetrapods, true internal gills are absent so that aortic arches do not break up into afferent and efferent arteries. I and II arches totally disappear in all tetrapods.

Amphibians. With the introduction of lungs as main respiratory organs and the diminishing importance of gills, the aortic arches of amphibians show a modification from those of fishes.

Urodeles or the tailed amphibians live in water and retain external gills permanently in

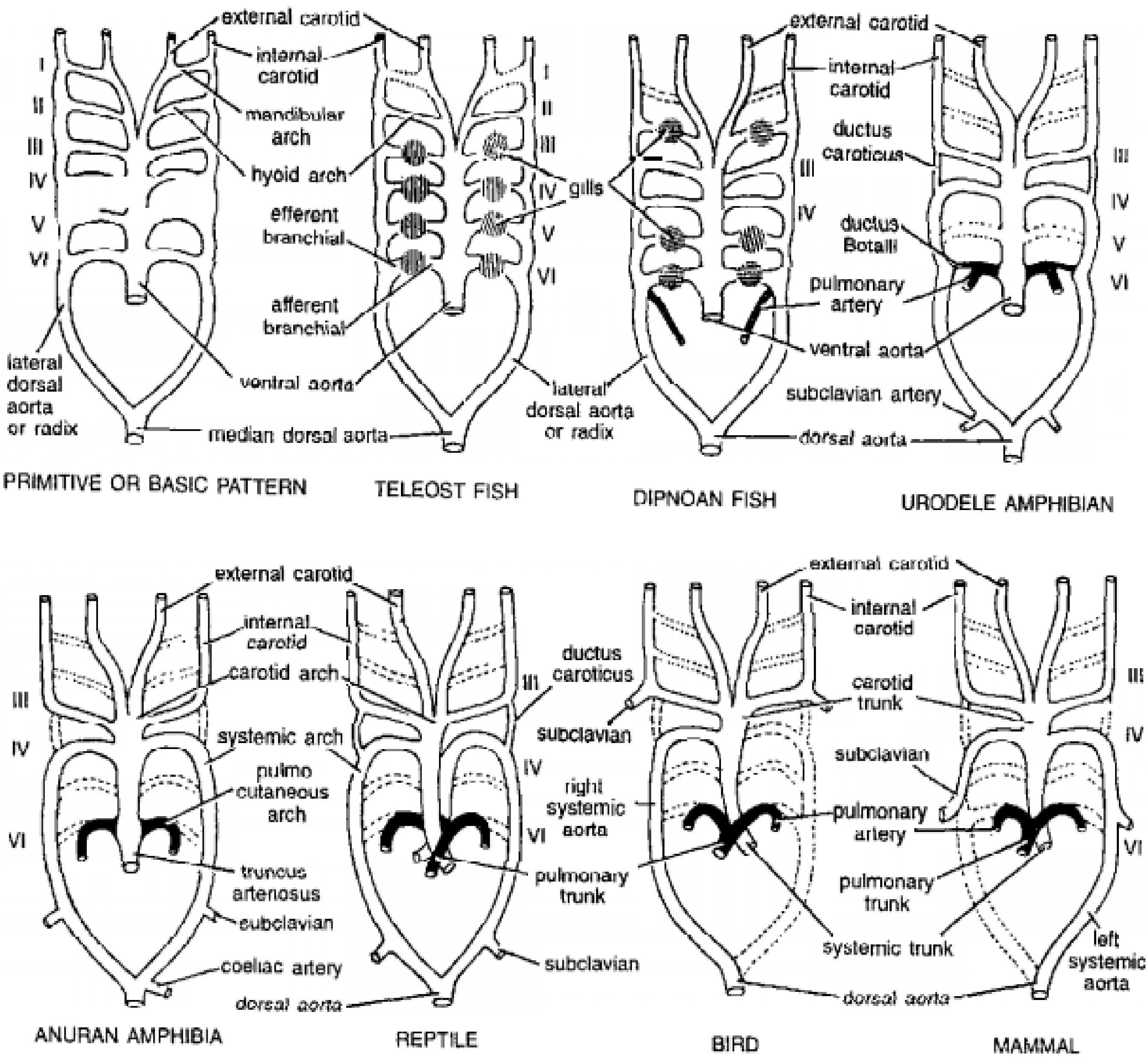

Fig. 4. Modification of aortic arches in respresentative vertebrates.

addition to lungs. Accordingly, their aortic system shows only partial shift from condition in fishes. 4 pairs of arches (III to VI) are usually present, although in some forms (*Necturus*, *Siren*, *Amphiuma)*, V arch is incomplete, reduced or absent. Thus tailed amphibians show transition from 4 to 3 pairs of aortic arches. III arch forms the *carotid arches*, IV the *systemic arches*. The radix or lateral aorta between III & IV arches may persist as a vascular connection termed *ductus caroticus*. VI arch on either side becomes the *pulmocutaneous artery* or *arch*, supplying blood to skin and lungs. However, it also retains connection with radix aorta called *ductus Botalli* or *ductus arteriosus*.

In the larval stage of an anuran or tailless amphibian, such as frog tadpole, arrangement of aortic arches is similar to an adult urodele, due to gill respiration. At metamorphosis, with loss of gills, aortic arches I, II and V disappear altogether. Ductus caroticus also disappears so that the III or carotid arch takes oxygenated blood only to head region. IV or systemic arch on each side continues to dorsal aorta to distribute blood elsewhere except head and lungs. Ductus arteriosus also disappears so that VI or pulmocutaneous arch supplies venous blood exclusively to lungs and skin for purification. Thus, adult anurans exhibit only 3 functional arches, (III, IV and VI) which are also retained by the amniotes or higher vertebrates.

Reptiles. Reptiles are fully terrestrial vertebrates in which gills disappear altogether and replaced by lungs. Only 3 functional arches (III, IV and VI) are present. But elongation of neck, posterior shifting of heart and partial division of ventricle brings about certain innovations in the aortic system.

(1) Entire ventral aorta and conus split forming only 3 trunks-two aortic or systemic and one pulmonary.

(2) *Right systemic arch* (IV) arises from left ventricle carrying oxygenated blood to the *carotid arch* (III) to be sent into head.

(3) *Left systemic arch* (IV) leads from right ventricle carrying deoxygenated or mixed blood to the body through dorsal aorta.

(4) *Pulmonary trunk* (VI) also emerges from right ventricle carrying deoxygenated blood to the lungs for purification.

(5) Ductus caroticus and ductus arteriosus are absent. But, ductus caroticus is present in certain snakes and lizards (*Uromasitx*), ductus arteriosus in some turtles, and both in *Sphenodon*. Reptiles also remain cold-blooded, like amphibians and fishes, due to mixing of blood.

Birds and mammals. Birds and mammals are warm-blooded because in both the ventricle is completely divided so that there is no mixing of oxygenated and unoxygenated bloods. As usual, 6 arches develop in the embryo, but only 3 arches (III, IV, VI) persist in the adult. Other features are as follows —

(1) Ventral aorta is replaced by two independent aortae or trunks-systemic and pulmonary.

(2) Arch IV is represented by a single *systemic aorta*, right in birds and left in mammals, emerging from left ventricle and carrying oxygenated blood. Uniting with the radix aorta of its side it forms the dorsal aorta.

(3) The only remaining part of the other lost systemic arch is represented by a *subclavian artery*, on left side in birds and on right side in mammals.

(4) Arch III with remnants of lateral and ventral aortae represents *carotid arteries*, which arise from systemic aorta.

(5) Arch VI forms a single *pulmonary trunk* taking deoxygenated blood from right ventricle to the lungs.

(6) Embryonic *ductus caroticus* and *ductus arteriosus* also disappear. The latter closes but persists until hatching or birth in some cases as a *thin ligament of Botalli* or *ligamentum arteriosum*.

Venous System

Deoxygenated or venous blood from different parts of the body is returned to the heart via veins. Like arteries, the veins of all vertebrates also follow a basic pattern or fundamental plan.

[I] Embryonic veins

The venous system in early embryonic life of all vertebrates is relatively simple, similar and in accordance with the basic pattern. Most of the veins are paired and symmetrically arranged. The major basic embryonic veins include : (i) *Cardinals* (anterior, posterior, and common cardinal or ductus Cuvieri), (ii) *lateral abdominal*, (iii) *vitelline*, (iv) *subintestinal*, and (v) *caudal*.

[II] Modifications of veins in vertebrates

Modifications in adult vertebrates occur by either deletions or additions of some veins to the basic embryonic pattern (Fig. 5). Modifications are few in elasmobranchs but more numerous in tetrapods. In vertebrates, veins can be arranged in three distinct categories– *systemic* or *somatic*, *renal portal* and *hepatic portal*. A fourth category of *pulmonary veins* and *postcaval veins* in added in lungfishes and tetrapods.

1. Systemic veins. Systemic or somatic veins collect blood from all parts of the body and empty into sinus venosus of the heart.