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COMPARATIVE ANATOMY OF AORTIC ARCHES IN VERTEBRATES

Introduction: The aortic arches or pharyngeal arch arteries are a series of six paired vascular structures which connect ventral aorta to the dorsal aorta and arise from the aortic sac.

Basic Plan

The basic fundamental plan of the aortic arches is similar in different vertebrates during embryonic stages. But in adult the condition of the arrangement is changed either being lost or modified considerably. The number of aortic arches is gradually reduced as the scale of evolution of vertebrates is ascended.

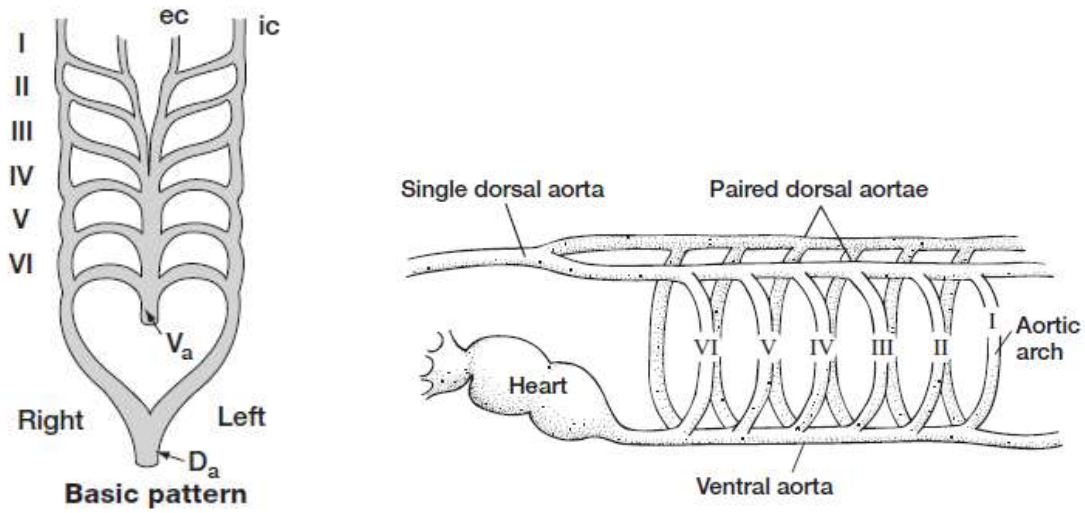


Fig. Primitive pattern of aortic arches. Diagram of the basic six-arch pattern. (Da= Dorsal Aorta; Va= Ventral Aorta; ec= external Carotid; ic= internal carotid)

Development of the basic pattern and associated arteries

I. The first pair of aortic arches is formed by the curving of the ventral aorta into the primitive dorsal aorta. This arch is hidden in the mandibular arch and participates in formation of the *maxillary artery*, and contribute to the *external carotid artery*

II. The second pair of aortic arches make their appearance in the middle of week 4. They cross the second branchial arches and give rise to the *stapedial* and *hyoid arteries*.

III. The third pair of aortic arches make their appearance at the end of week 4. They give rise to the *common carotids* and *proximal portions of the internal carotid arteries*. The latter are the short cephalic prolongations of the primitive dorsal aortas and are associated with development and supply of the brain

   A. THE INTERNAL CAROTID ARTERIES are secondarily attached to the cranial portions of the dorsal aortas, which form the remainder of the carotid artery

   B. THE ORIGIN OFTHE EXTERNAL CAROTID ARTERIES is controversial, but in later stages of development, they are found to sprout from aortic arch II (Arch I, however, has been implicated in its developmental contribution)

IV. The fourth pair of aortic arches make their appearance shortly after the third arches, at the end of week 4. Their development is different for the right and left sides

A. ON THE RIGHT SIDE arch IV forms the proximal portion of the right subclavian artery and is continuous with the seventh segmental artery

1. The caudal portion of the right primitive dorsal aorta disappears
2. The distal portion of the subclavian artery forms from the right dorsal aorta and the right seventh intersegmental artery

B. ON THE LEFT SIDE arch IV persists as the *arch of the aorta*, which grows significantly and is continuous with the primitive left dorsal aorta.

1. The *left subclavian artery* (or seventh segmental) arises directly from the aorta

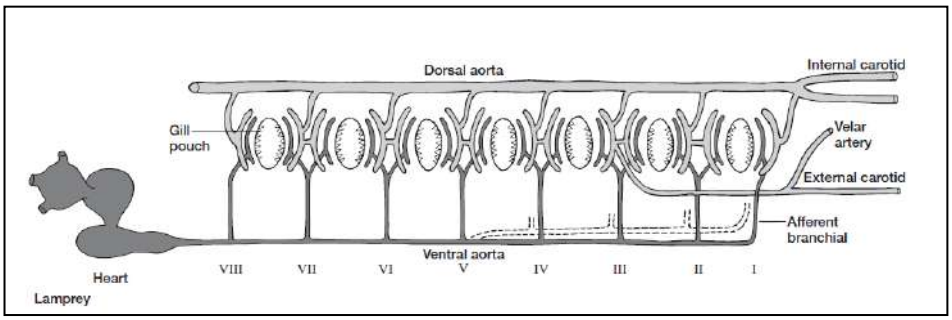
C. THE SHORT PORTION of the right primitive ventral aorta, which persists between arches IV and VI, forms the *brachiocephalic arterial trunk* and the *first portion of the aortic arch*

V. The fifth pair of aortic arches: in 50% of embryos, these arches are rudimentary vessels that degenerate with no derivatives. In fact, they may never even develop.

VI. The sixth pair of aortic arches make their appearance in the middle of week 5 and give rise to the *right* and *left pulmonary arteries.* After pulmonary vascularization is established, the communication with the corresponding primitive dorsal aorta regresses.

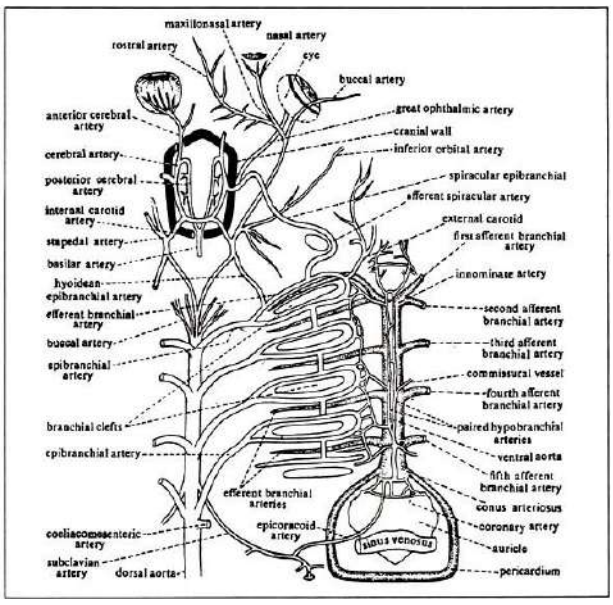
Modifications in different vertebrate groups

Cyclostomes:



1. In lampreys (Petromyzon) there are eight pairs of aortic arches and in hag fishes (Bdellostoma) there are fifteen pairs. The aor-tic arch is divided into afferent branchial artery and efferent branchial artery.
2. In lampreys each aortic arch divides and sends branches to the posterior hemi-branch and anterior hemi-branch of the adjacent gill pouch. In hagfishes each arch supplies to the hemi--branch of a single gill-pouch.

Elasmobranchs:



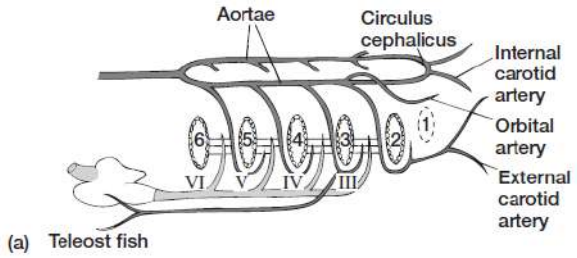
1. Generally there are five pairs of aortic arches in elasmobranchs but in some cases there is a variation. In Hexanchus there are six pairs of aortic arches. In Heptranchias there are seven pairs.
2. In elasmobranchs the first pair of aortic arches (mandibular) disappear. Second to sixth pair of aortic arches (II-VI) persist as branchial arteries. Each aortic arch is divided into afferent and efferent branchial arteries.
3. Five pairs afferent arteries arise from ventral aorta and supply deoxygenated blood to the respective gills. The ventral aorta divides into two branches, called innominate arteries which again

bifurcate into the first and second afferent branchial arteries. From the gills the oxygenated blood is collected by efferent branchial arteries.

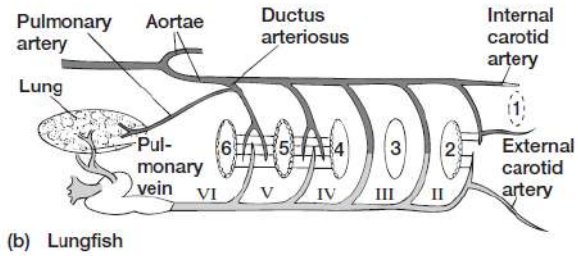
4. In elasmobranchs there are nine pair's efferent branchial arteries of which the first eight arteries form a series of four complete loops but ninth efferent branchial artery collects blood from the demi- branch of the fifth gill pouch.

Teleosts:

1. In teleosts there are four pairs of aortic arches. First pair (mandibular) and second pair (hyoidean) are lost, only four pairs (third to sixth) persist as branchial arteries. Four pairs afferent branchial arteries arise from the ventral aorta.



(a) Teleost fish



(b) Lungfish

2. They supply deoxygenated blood to the gills for aeration. The ventral aorta bifurcates anteriorly to form the first pair of afferent branchial arteries. In sturgeon (Acipenser) and Amia each afferent branchial arch bifurcates as in elasmobranchs.

Dipnoans:

1. In lungfishes, as in other bony fishes, the first pharyngeal slit is reduced to a spiracle that has no respiratory function.
2. Its associated aortic arch (I) is reduced as well as the IInd arch.
3. In the Australian lungfish, Neoceratodus, the remaining five pharyngeal slits open to fully functional gills supplied by four aortic arches (III–VI).
4. In the African lungfish, Protopterus, the functional gills are reduced further. The third and fourth gills are absent entirely, but their aortic arches (III–IV) persist.
5. In all lungfishes, the efferent vessel of the most posterior aortic arch (VI) gives rise to the pulmonary artery but maintains its connection to the dorsal aorta via the short ductus arteriosus.

Amphibians:

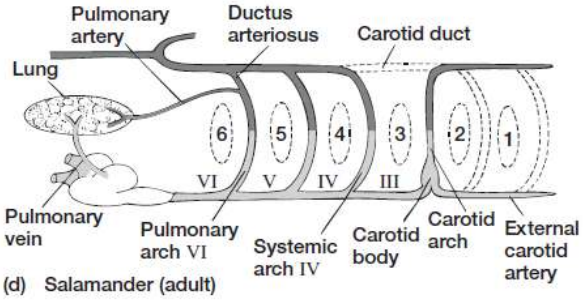
In amphibians, the first two aortic arches (I, II) disappear early in development. The pattern of the remaining arches differs between larvae and metamorphosed adults.

A. Urodales:

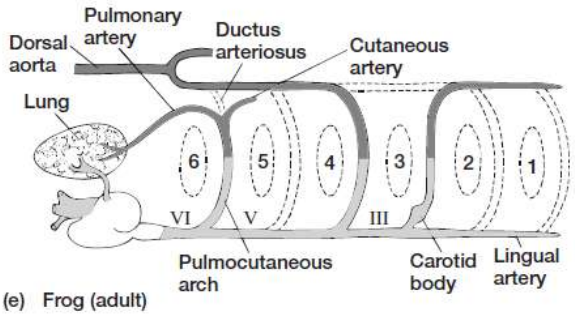
1. In most larval salamanders, the next three aortic arches (III–V) carry external gills, and the last aortic arch (VI) sprouts the pulmonary artery to the developing lung.
2. A notable exception is the neotenic salamander Necturus, in which part of the sixth arch disappears and only its dorsal section persists, forming the base of the pulmonary artery. In most species of salamanders, the external gills are lost following the larva's transformation into the adult, but the aortic arches are retained as major systemic vessels.
3. The short section of dorsal aorta between aortic arches III and IV, termed the carotid duct, usually closes at metamorphosis. This forces the carotids to fill with blood from a derivative of the ventral aorta. The section of ventral aorta between arches III and IV becomes the common carotid artery, which feeds the external

carotid (from the anterior ventral aorta) and the internal carotid (the anterior section of the dorsal aorta together with the third aortic arch).

4. The carotid body is a small cluster of sensory cells associated with capillaries, usually located near the point at which the common carotids branch. Its functions are not completely known. Certainly the carotid body plays a role in sensing the gas content or pressure of the blood as well as having some endocrine functions.



(d) Salamander (adult)



(e) Frog (adult)

5. The next two arches (IV, V) constitute major systemic vessels that join the dorsal aorta.

6. The final aortic arch (VI) also joins the dorsal aorta, its last short section forming the ductus arteriosus. Shortly before joining the dorsal aorta, the sixth aortic arch gives off the pulmonary artery, which itself divides into small branches to the floor of the mouth, pharynx, and esophagus before actually entering the lungs.

7. In lungless salamanders, the pulmonary artery, if it persists, supplies the skin of the neck and back.

b. Anurans:

1. In frogs, the larva usually has internal gills that reside on the last four aortic arches (III–VI), and the embryonic pulmonary artery buds from arch VI. At metamorphosis, these gills are lost together with the carotid duct and all of arch V.
2. The aortic arches that persist (III, IV, and VI) expand to supply blood to the head, body, and pulmonary circuits, respectively.
3. The third arch and associated section of anterior dorsal aorta become the internal carotid. The anterior extension of the ventral aorta is the external carotid. Internal and external carotids both branch from the common carotid, the section of ventral aorta between arches III and IV.
4. A carotid body can usually be found at the root of the internal carotid. The next enlarged aortic arch (IV) joins with the dorsal aorta, the major systemic artery supplying the body.
5. The last arch (VI) loses its connection to the dorsal aorta because the ductus arteriosus closes and becomes the pulmocutaneous artery. One branch of the pulmocutaneous artery is the now well-developed pulmonary artery that enters the lung. The other branch is the cutaneous artery, which delivers blood to the skin along the dorsal and lateral body wall.

Reptiles

1. Beginning in reptiles, but carried into birds and mammals, the symmetrical aortic arches of the embryo tend to become asymmetrical in the adult. Aortic arches III, IV, and VI persist in reptiles, but most of the changes center on enhancements and modification of the fourth arch.
2. Perhaps the most significant anatomical modification of the arterial system in reptiles is the subdivision of the ventral aorta. During embryonic development, the ventral aorta splits to form the bases of three separate arteries leaving the heart: the left aortic arch, the right aortic arch, and the pulmonary trunk.
3. The base of the left aortic arch, the left aortic arch (IV) itself, and the curved section of the left dorsal aorta into which it continues constitute the left systemic arch. The right systemic arch includes the same components on the right side of the body: the base of the right aortic arch, the right aortic arch itself, and the

arched section of the right dorsal aorta. The two systemic arches unite behind the heart to form the common dorsal aorta.

4. The right systemic arch tends to be the most prominent of the two, primarily because of the additional vessels that it supplies. For example, the carotid arteries, originating from the ventral aorta in more primitive vertebrates, arise in reptiles from the right systemic arch. Blood passing through the right systemic arch might flow to the body or enter the carotid arteries to supply the head.
5. In most reptiles, the subclavian arteries branch from the dorsal aorta, but in some reptiles, they branch from the systemic arches. These modifications of the aortic arches in reptiles produce one pulmonary circuit and two systemic circuits, each of which arises independently from the heart.
6. The pulmonary trunk incorporates the bases of the paired sixth arch and their branches as part of the pulmonary arch to the lungs.

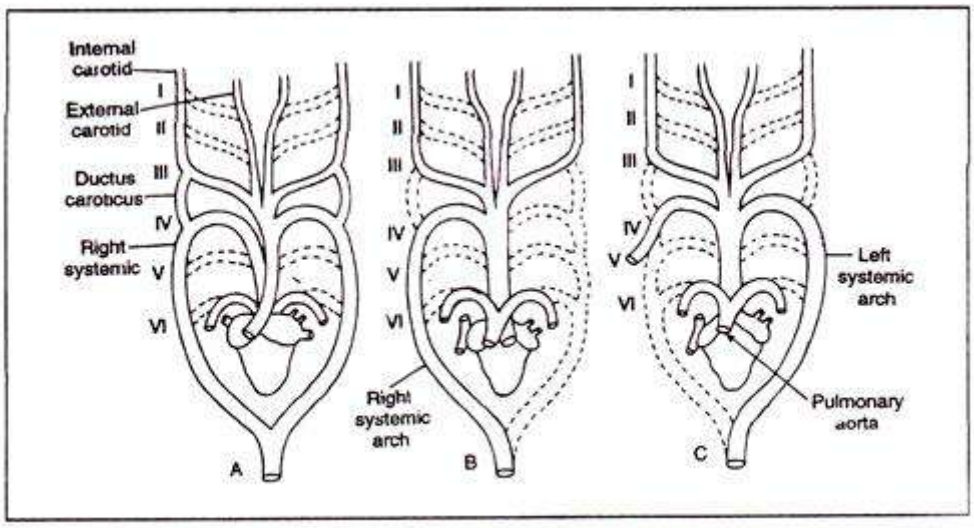


Fig. 10.147 : Aortic arches. A. Reptiles (Lizards), B. Birds, C. Mammals.

Birds

1. In birds, the right systemic arch becomes predominant. The bases of the aortic arch, the right aortic arch (IV), and the adjoining section of the right dorsal aorta form the right systemic arch during embryonic development.
2. Its opposite member, the left systemic arch, never fully develops.
3. The carotids arise generally from the same components of the aortic arches as in reptiles (aortic arch III and parts of the ventral and dorsal aortae), and they branch from the right systemic arch. However, the paired subclavians to the wings arise from the internal carotids and not from the dorsal aorta.
4. The common carotids and subclavians supply the head and forelimbs, respectively. The common carotids can branch from the right systemic arch separately, or both can join to form a single carotid.
5. A short but major vessel, the brachiocephalic artery, is present in a few reptiles, especially turtles, but serves as the major anterior vessel in many birds. It too branches from the right systemic arch. Beyond this junction of the brachiocephalic artery, the systemic arch curves posteriorly to supply the rest of the body. In birds as in reptiles, the pulmonary arch forms from the bases of the paired sixth arch and their branches to supply both lungs.

Mammals

1. Up to six aortic arches arise in the mammalian embryo, but only three persist in the adult as the major anterior arteries: the carotid arteries, the pulmonary arch, and the systemic arch.

2. The carotid arteries and pulmonary arch are assembled from the same arch components as those of reptiles. The mammalian carotids arise from the paired aortic arches (III) and parts of the ventral and dorsal aortae.
3. The pulmonary arch forms from the bases of the paired sixth arch and its branches.
4. The systemic arch arises embryonically from the left aortic arch (IV) and left member of the paired dorsal aorta, and therefore is a left systemic arch in mammals. The common carotids may share a brachiocephalic origin or branch independently from different points on the aortic arch.
5. The other notable difference in mammals is in the formation of the subclavian arteries. The left subclavian departs from the left systemic arch in mammals. The right subclavian, however, includes the right aortic arch (IV), part of the adjoining right dorsal aorta, and the arteries that grow from these into the right limb.

Evolutionary Significance of Aortic Arches

a) In most fishes, the aortic arches deliver deoxygenated blood to the respiratory surfaces of the gills and then distribute oxygenated blood to tissues of the head (via the carotids) and remainder of the body (via the dorsal aortae).
b) In lungfishes and tetrapods, the aortic arches contribute to the pulmonary arch, the arterial circuit to the lungs, and the systemic arches, the arterial circuits to the rest of the body. The carotid arteries still bear the primary responsibility for supplying blood to the head in tetrapods, but now they usually branch from one of the major systemic arches.
c) The double systemic arches (left and right) present in amphibians and reptiles become reduced to a single systemic arch— the right in birds, the left in mammals.
d) Although birds and mammals share many similarities, including endothermy, active lives, and diverse radiation, they arose out of different reptilian ancestries. Any similarities in their cardiovascular anatomies represent independent evolutionary innovations.
e) The basic six-arch pattern of aortic arches is a useful concept that allows us to track aortic arch derivatives and organize the diversity of anatomical modifications we encounter. Furthermore, the appearance of six aortic arches during the embryonic development of living gnathostomes suggests that this is the ancestral pattern.
f) However, as we have seen, the actual adult anatomy can be quite varied among different species.

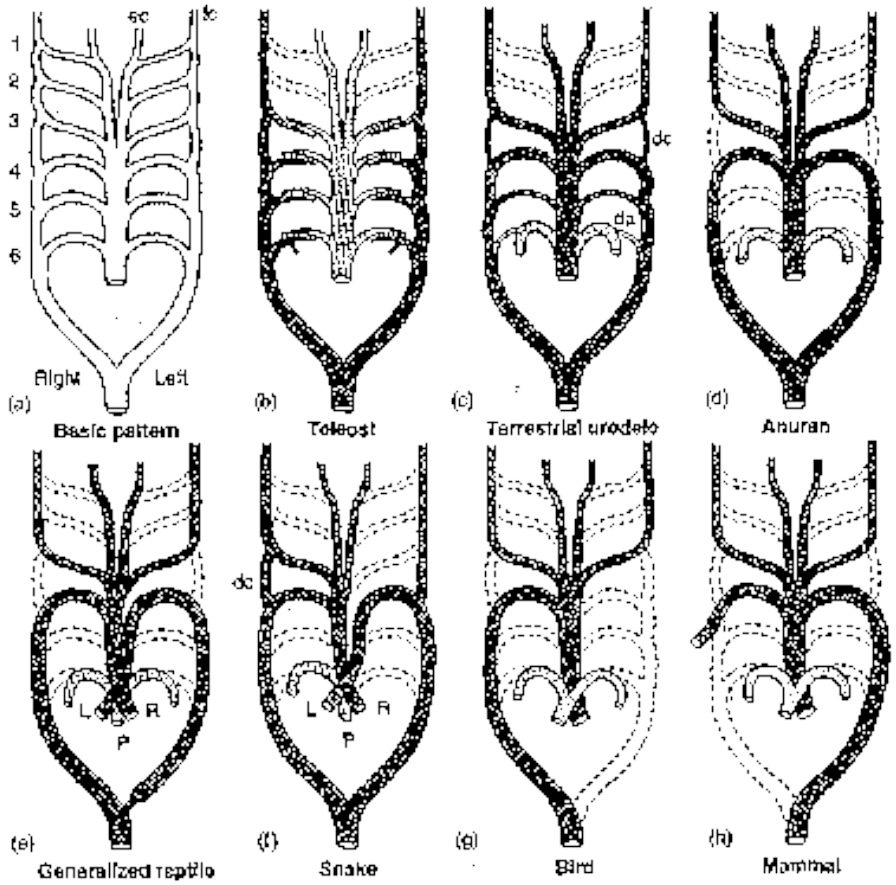


Table 2.2 : The modifications of embryonic aortic arches in adult vertebrates

Embryonic aortic arches	Elasmo-branchs	Teleosts	Lower Amphibians	Higher Amphibians	Reptiles	Birds	Mammals
First pair	Disappear	Disappear	Disappear	Disappear	Disappear	Disappear	Disappear
Second pair	Persist as first branchial arteries	Disappear	Disappear	Disappear	Disapper	Disapper	Disappear
Third pair	Persist as second branchial arteries	Persist as first branchial arteries	Persist as carotid arteries	Persist as carotid arteries	Persist as carotid arteries	Same as reptiles	Same as birds
Fourth pair	Persist as third branchial arteries	Persists as second branchial arteries	Persist as left and right systemic arteries	Persist as left and right systemic arteries	Persist as right and left systemic arteries	Persist only as right systemic artery	Persist only as left systemic artery
Fifth pair	Persist as fourth branchial arteries	Persist as third branchial arteries	Persist as branchial arteries	Disappear	Disappear	Disappear	Disappear
Sixth pair	Persist as fifth branchial arteries	Persist as fourth branchial arteries	Persist as right and left pulmonary arteries	Persist as right and left pulmonary arteries	Persist as right and left pulmonary arteries	Persist as right and left pulmonary arteries	Same as birds