FIGURE 87. Conus arteriosus and afferent branchial arteries of the lungfish *Protopterus*. The spiral valve distributes oxygen-rich blood to the first 3 afferent branchial arteries (II, III, IV) and oxygen-poor blood to the last 2 (V, VI), which supply the respiratory swim bladder/lung and internal gills. Thus imperfect separation of a dual circuit circulatory system is established.
FIGURE 88. Basic arterial pattern in gnathostomes.
**FIGURE 89.** Primitive pattern of aortic arch arterial system in ganthostomes. Ventral aspect (left), Right lateral aspect (right).
A. Teleost Fish

B. Lungfish

**FIGURE 90.** Aortic arch derivatives of Teleosts and Lungfish.
A. Ventral and lateral aspects of the basic six-arch pattern in a teleost fish.
B. Ventral and lateral aspects of the basic six-arch pattern in a lungfish (*Protopterus*).
A. Lungfish

B. Urodele

**FIGURE 91.** Aortic arch derivatives of Lungfish and Salamanders.  
A. Ventral and lateral aspects of the basic six-arch pattern in a lungfish (*Protopterus*).  
B. Ventral and lateral aspects of the basic six-arch pattern in a urodele. Ventral and lateral aortic arch systems of terrestrial, adult salamanders at left, bottom. Lateral aortic arch system of an aquatic larval salamander at top. *da*, *ductus arteriosus*; *dc*, *dusctus caroticus*. 
**FIGURE 92.** Aortic arch derivatives of Salamanders and Frogs.

A. Ventral and lateral aspects of the basic six-arch pattern in a urodele. Ventral and lateral aortic arch systems of terrestrial, adult salamanders at left, bottom. Lateral aortic arch system of an aquatic larval salamander at top. B. Ventral and lateral aspects of the basic six-arch aortic system in an adult anuran. Note the pulmocutaneous or cutaneous artery which branches to the skin. When adult frogs dive, a sphincter prevents blood flow to the lung by diverting blood flow to the skin to increase cutaneous respiration. *da, ductus arteriosus; dc, ductus caroticus.*
FIGURE 93. Amphibian hearts. A. Diagram of a typical amphibian heart. Notice that the atrium is divided into left and right chambers but the ventricle lacks an internal septum.

B. Heart of Rana catesbeiana, the bullfrog. Notice the small ventricular folds or trabeculae. With the aid of the spiral valve, these folds aid in separating systemic and pulmonary bloodstream as they pass through the heart. Black arrows demonstrate the flow of oxygenated blood through the heart. White arrows trace the flow of deoxygenated blood through the heart.
FIGURE 94. Heart and aortic arches of frog, ventral view. A. *In situ* aspect of heart and supporting arterial network. B. Detail of conus arteriosus opened to show spiral valve and passageways to left carotid arch (arrow a-a) and left systemic arch (arrow b-b). Arrow c enters common passageway to left and right pulmonary arches, then turns to enter passageway to left pulmonary arch.
**FIGURE 95.** Lobe-finned limbs of the late Devonian Rhipidistian *Eusthenopteron*. Legs of modern tetrapods evolved from similar fins in Paleozoic fishes. In *Eusthenopteron*, the anterior fin contained an upper arm bone (humerus), two forearm bones (radius and ulna), and a series of smaller elements (intermedium and ulnare) that are homologous to the carpal wrist bones of tetrapods. The dermal fin rays are homologous to phalanges in tetrapods. However, the pectoral girdle was typical of fishes, consisting of a cleithrum, clavicle and other bones fused to the skull.
**FIGURE 96.** Early tetrapod limb of the early Devonian (360 MYA) ichthyostegalid amphibian *Acanthostega*. The ulnare and intermedium of the rhipidistians has been replaced by a true carpal series to form a modern wrist. The dermal fin rays of the rhipidistian model have been replaced by eight fully evolved fingers or phalanges. The pectoral girdle includes typical tetrapod scapula and clavical elements and is no longer fused to the skull. *Acanthostega* was probably exclusively aquatic because the limb structure is simply too weak for travel on land.
**Ichthyostega** (Ichthyostegalia)

**FIGURE 97.** Early tetrapod limb of the early Devonian (350 MYA) ichthyostegalid *Ichthyostega*. Girdle and limb structure in *Ichthyostega* is similar to that of *Acanthostega* except that the structure is more fully developed and provides a great deal more support and power for travel on land, thus *Ichthyostega* was probably able to walk on land although retention of the tail fin indicates a predominately aquatic existence. Digits on the hind feet are reduced to seven and the same number are presumed for the front limbs although no complete fossil has been found.
**FIGURE 98.** Early pentadactylyous tetrapod limb of the Carboniferous (300 MYA) anthracosaurian amphibian *Limnoscelis*. The anthracosaurians display full development of the pentadactyl tetrapod limb model that persists as the terapod standard. A developed, independent girdle system, single upper and paired lower limb long bones, carpal-based wrists and fully developed phalanges that are fixed at 5-digits per limb: the pentadactyl standard.
FIGURE 99. General pattern of the modern pentadactylous tetrapod limb: left front (left) and hind (right) limbs of a primitive reptile *Ophiacodon*. Roman numerals indicate digits. (after Romer)
Figure 100. Summary of pectoral girdle evolution. Notice that dermal elements (no shading) of the girdle tend to be lost, and endochondral elements (shaded) tend to assume a greater role. In primitive therapsids, a third endochondral bone appears, the posterior coracoid, to join with the phylogenetically older scapula and anterior coracoid bones. The three persist into primitive mammals. In marsupials and placental mammals, only the scapula and posterior coracoid (called just coracoid) persist. In modern reptiles and birds, the scapula and anterior coracoid (or procoracoid) persist. (from Kardong)