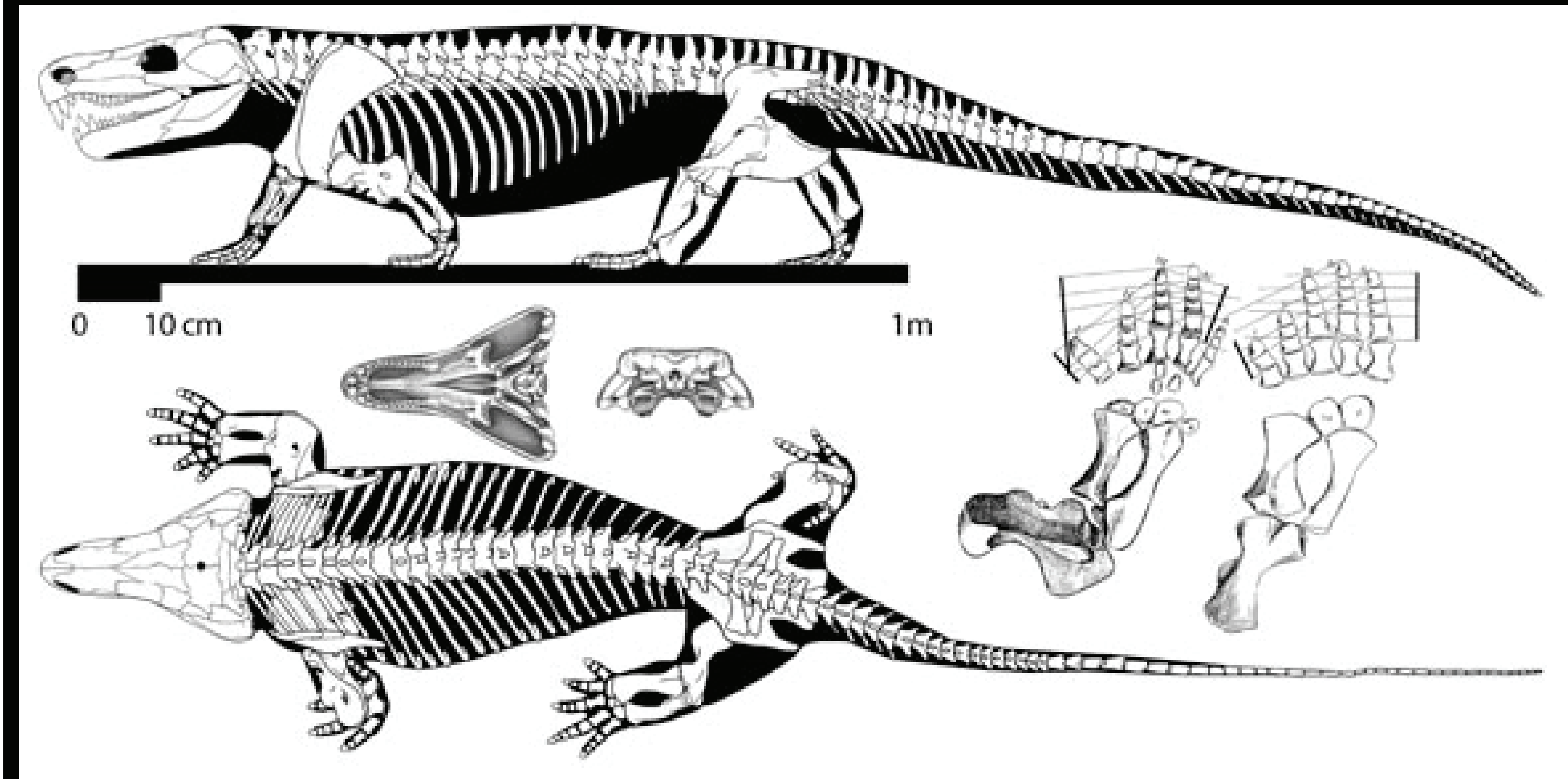
Comparative Anatomy & Evolution of Vertebrates



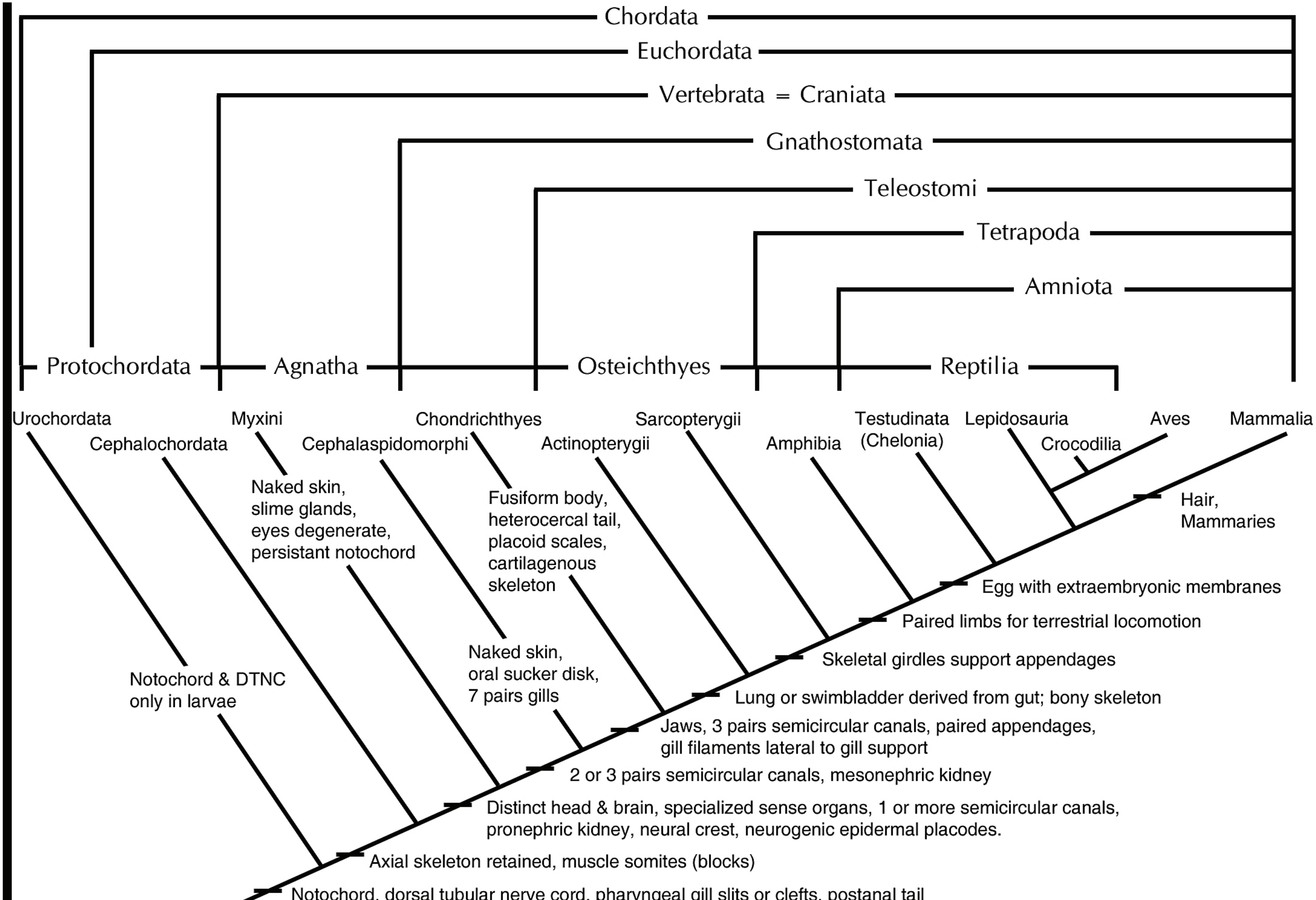


FIGURE 46. Cladogram of the living vertebrates. Functional group arrangements are depicted above the cladogram.

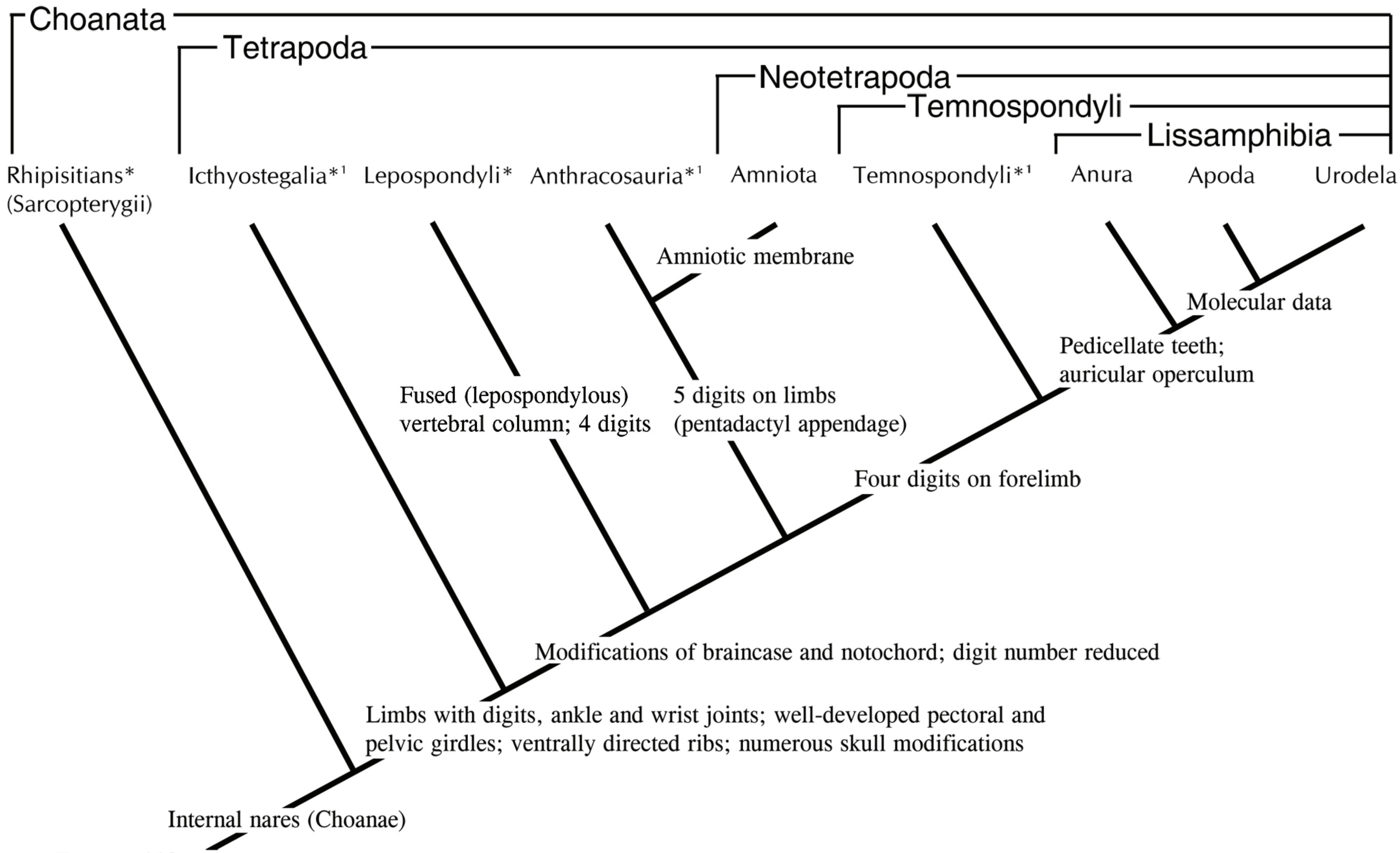


FIGURE 110. Cladogram of the Amphibians. The arrangement presented above assumes monophyly of the Lissamphibia and polyphyly among the Labyrinthodontia. Note that this arrangement weights the reduction of digits and utilizes molecular data to maintain monophyly of Lissamphibia.
* indicates extinct group; [1] member of the Labyrinthodontia

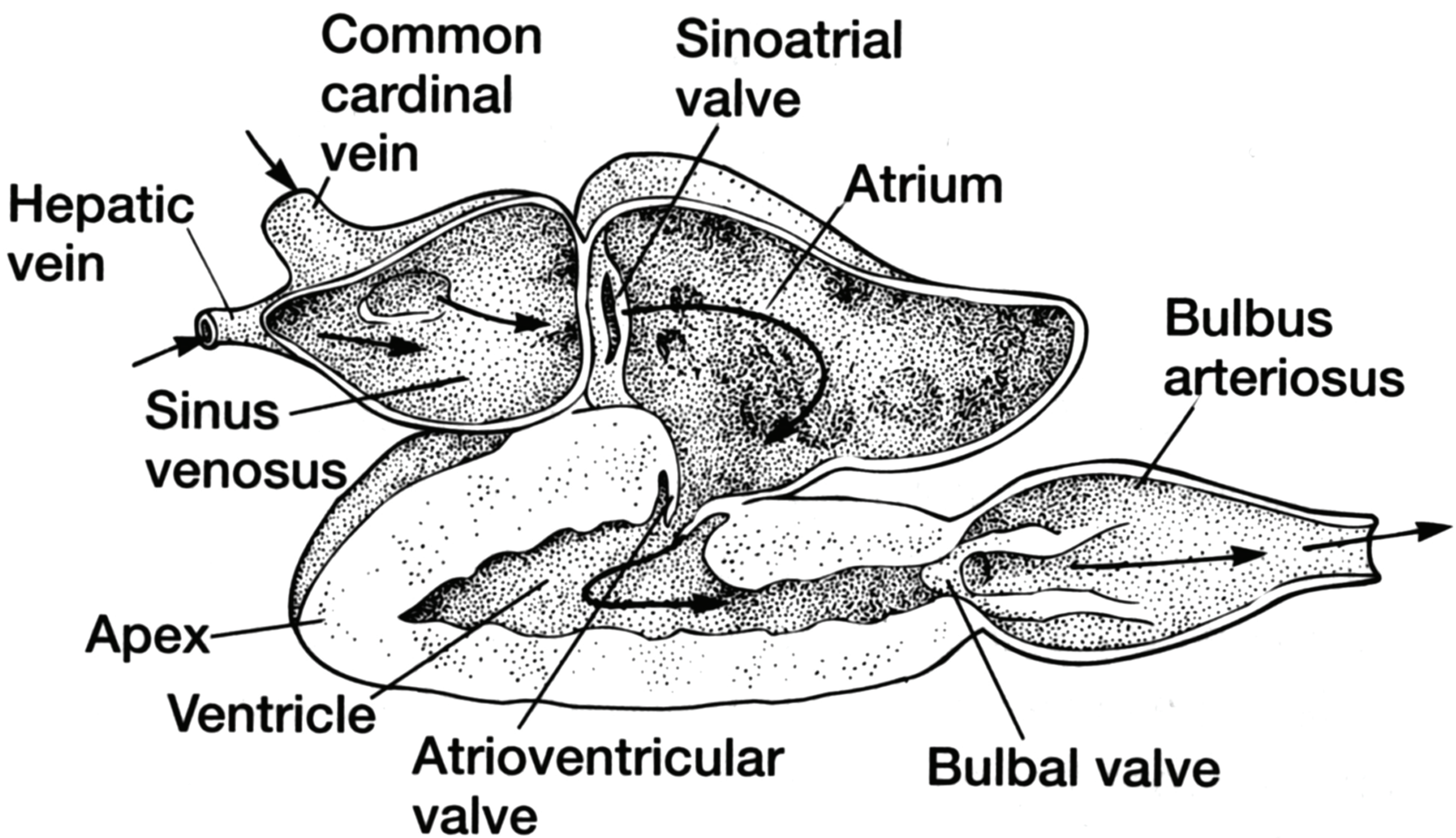


FIGURE 84. Teleost heart structure.

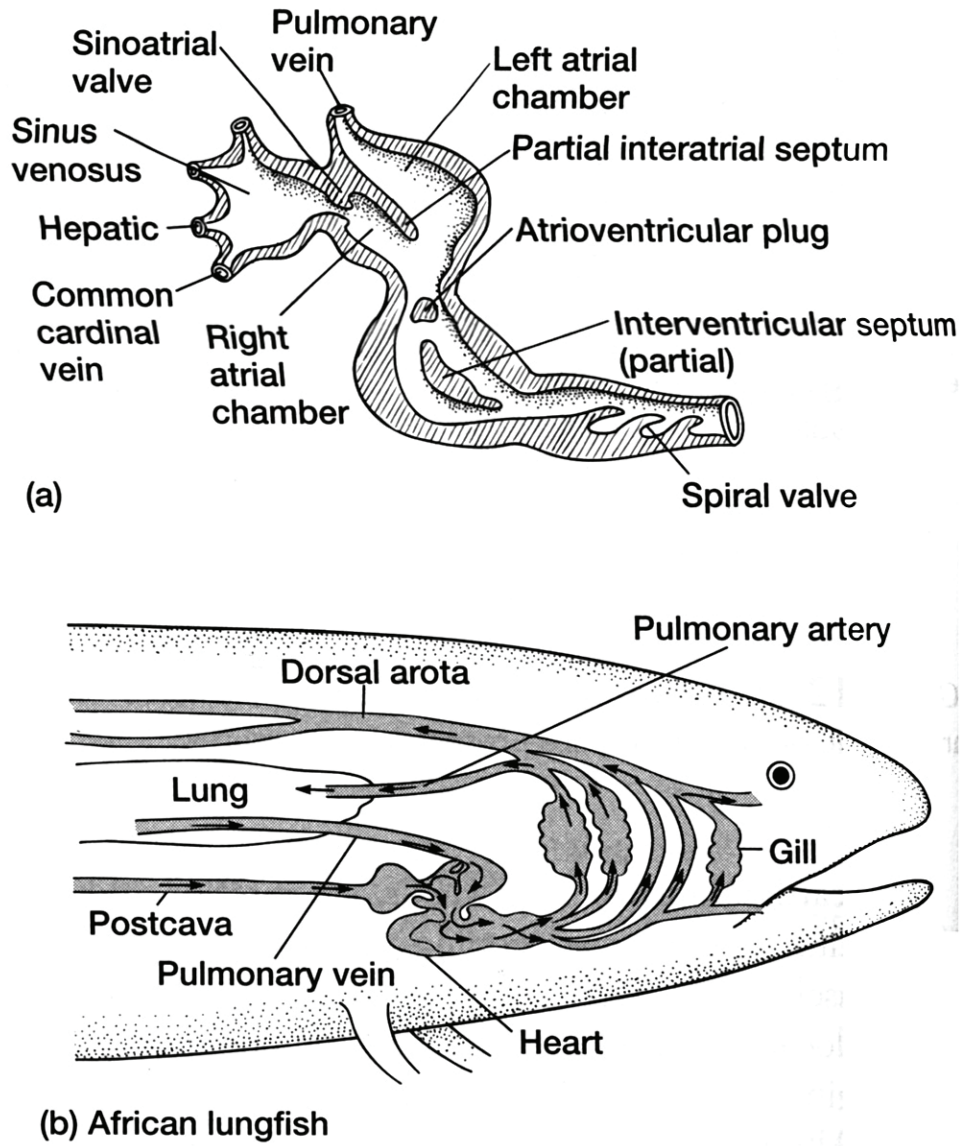


FIGURE 85. **Dipnoian heart structure: Heart of the African Lungfish *Protopterus.*** **A.** Internal structure of the heart. **B.** Path of blood flow. When the lungfish breathes air, venous bllod returning from the systemic tissues flows through the heart and tends to be directed to the last aortic arch (VI) where the pulmonary artery carries most of the deoygenated blood to the lung. Blood high in oxygen returning from the lung passes through the heart and then tends to enter aortic arches without gills (III, IV), shunting oxygenated blood to the general systemic circulation. Thus a primitive dual circuit circulatory system is acheived. The five aortic arches phylogenetically represent the 2nd through 6th arches (II-VI). Arches II, V, and VI carry gills.

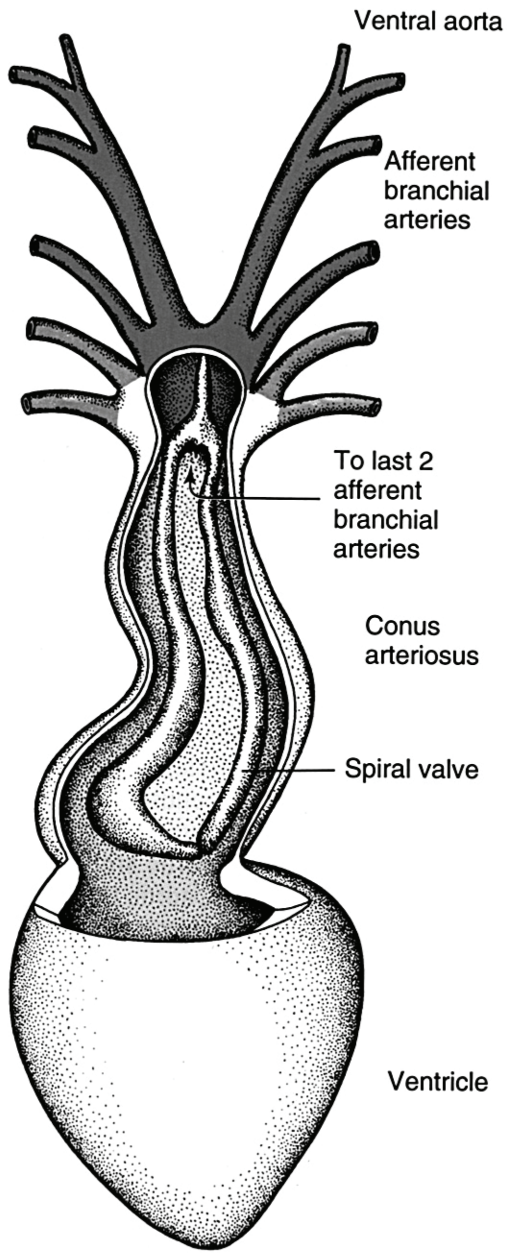


FIGURE 87. Conus arteriosus and afferent branchial arteries of the lungfish *Protopterus.* The spiral valve distributes oxygen-rich blood to the first 3 afferent branchial arteries (II, III, IV) and oxygen-poor blood to the last 2 (V, VI), which supply the respiratory swim bladder/lung and internal gills. Thus imperfect separation of a dual circuit circulatory system is established.

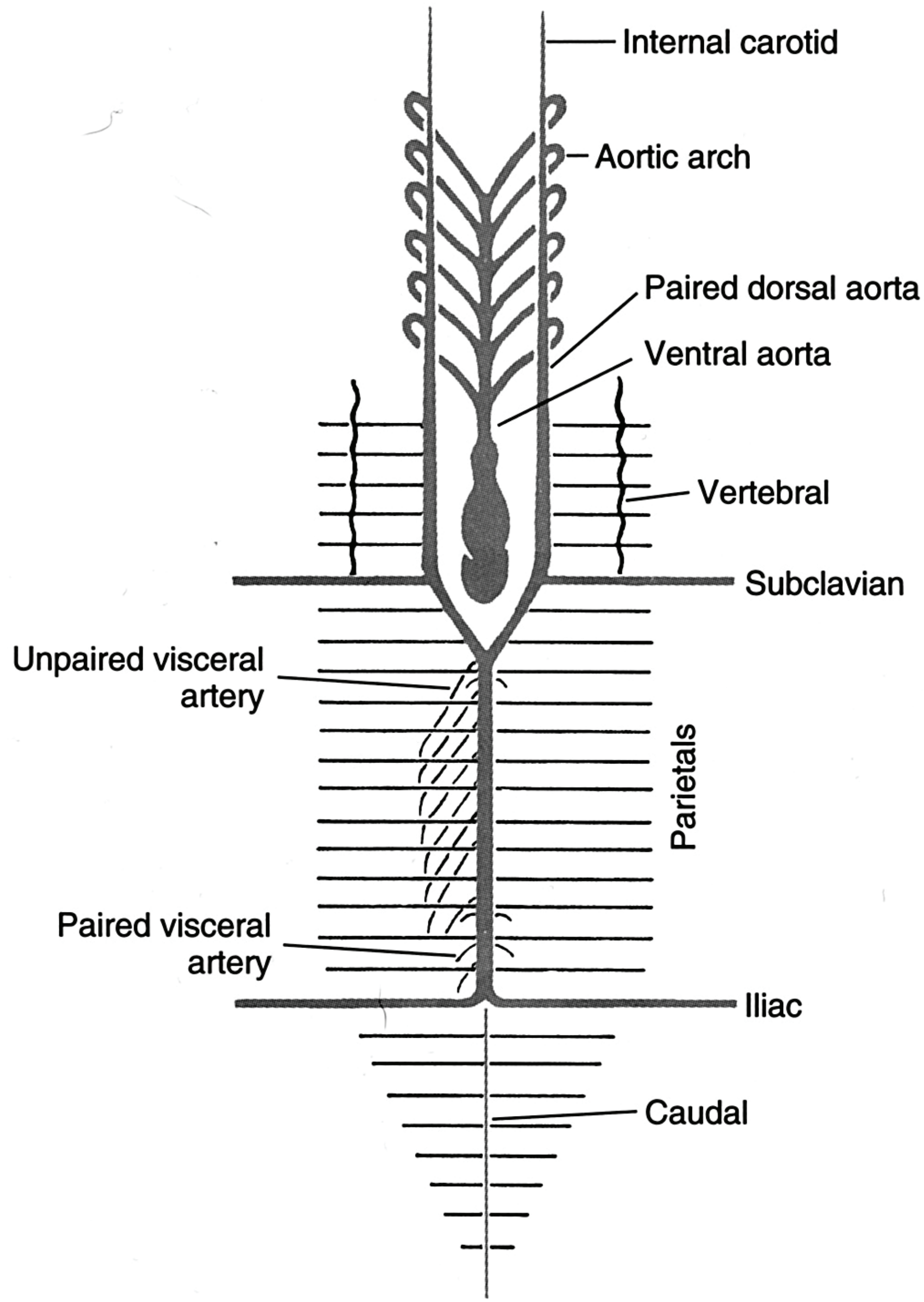


FIGURE 88. Basic arterial pattern in gnathostomes.

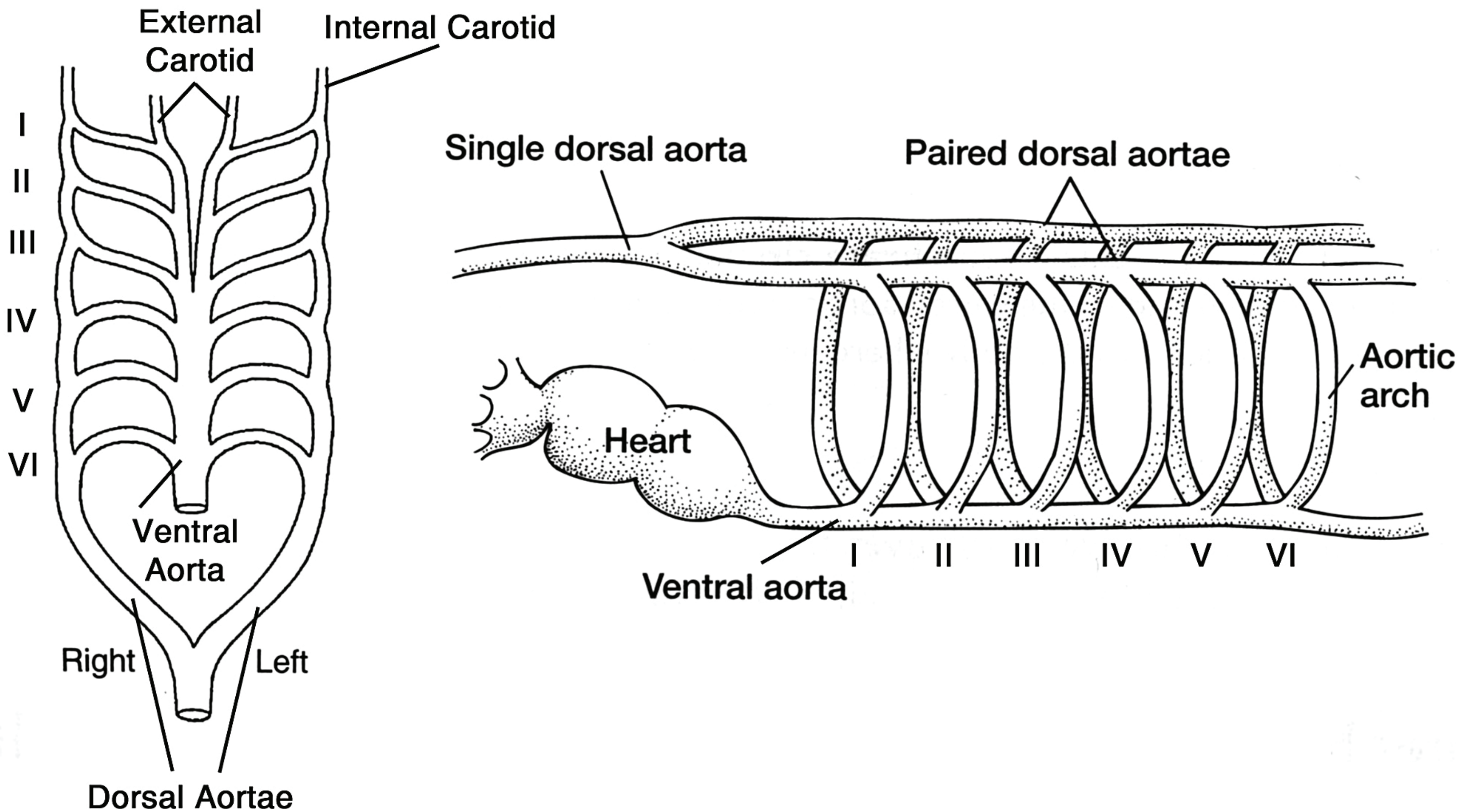


FIGURE 89. Primitive pattern of aortic arch arterial system in ganthostomes. Ventral aspect (left), Right lateral aspect (right).

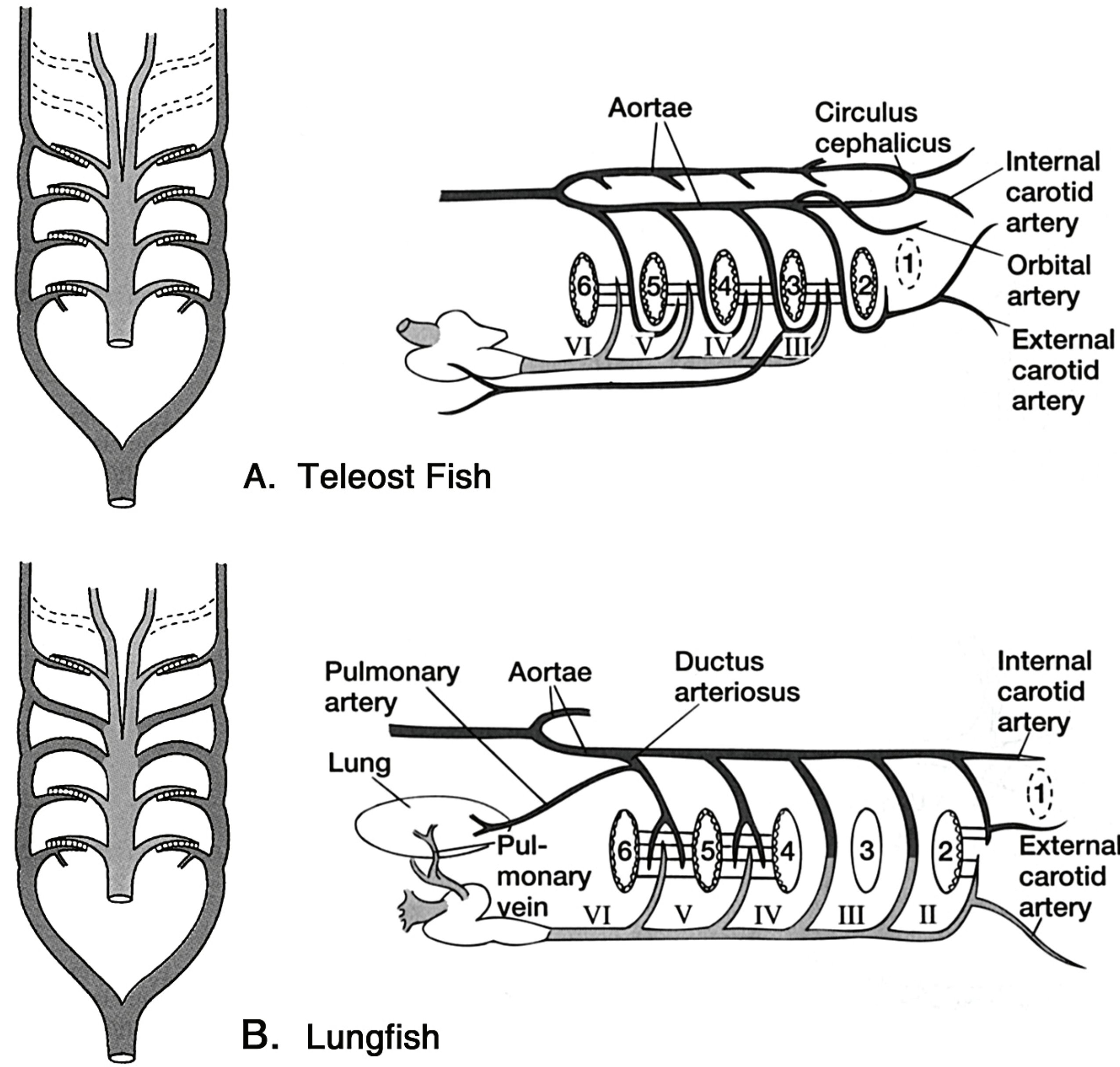


FIGURE 90. Aortic arch derivatives of Teleosts and Lungfish.
A. Ventral and lateral aspects of the basic six-arch pattern in a teleost fish.
B. Ventral and lateral aspects of the basic six-arch pattern in a lungfish (*Protopterus*).

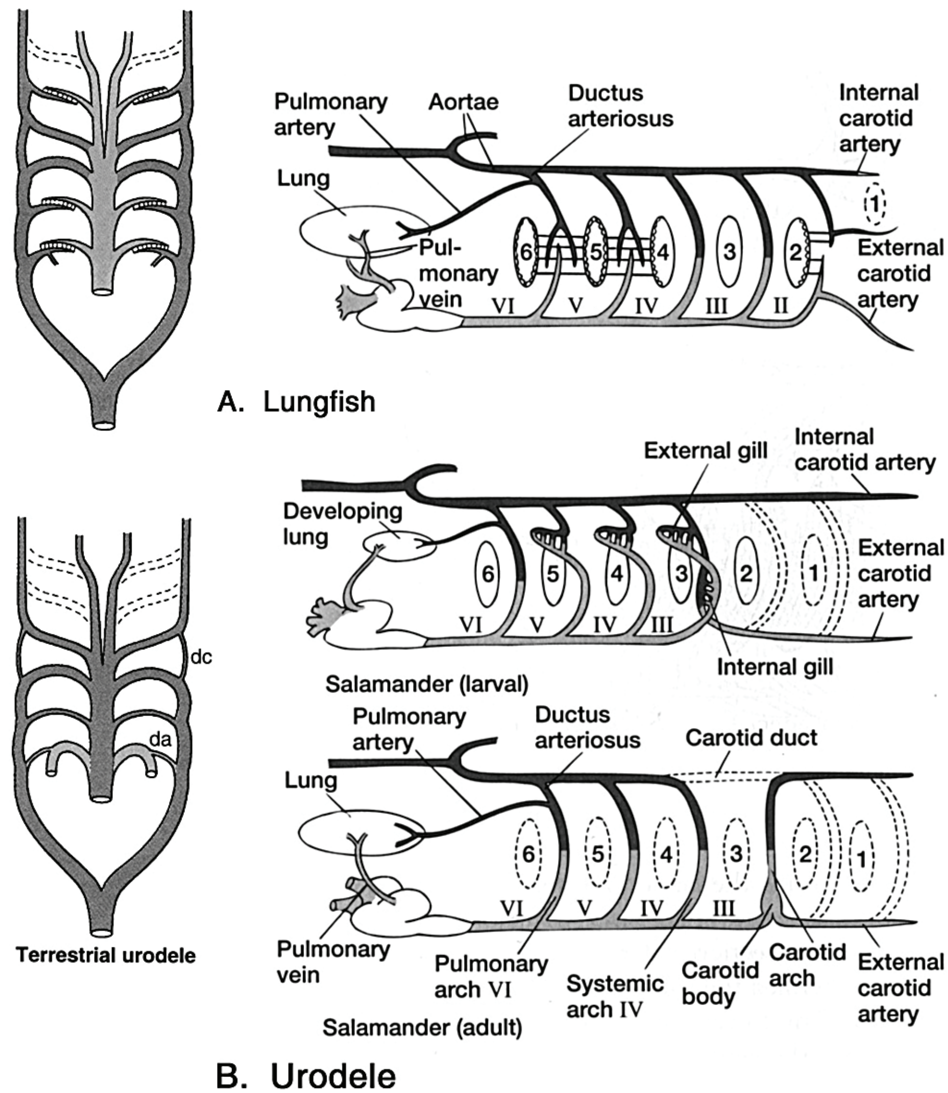


FIGURE 91. Aortic arch derivatives of Lungfish and Salamamders. **A.** Ventral and lateral aspects of the basic six-arch pattern in a lungfish (*Protopterus*). **B.** Ventral and lateral aspects of the basic six-arch pattern in a a urodele. Ventral and lateral arotic arch systems of terrestrial, adult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

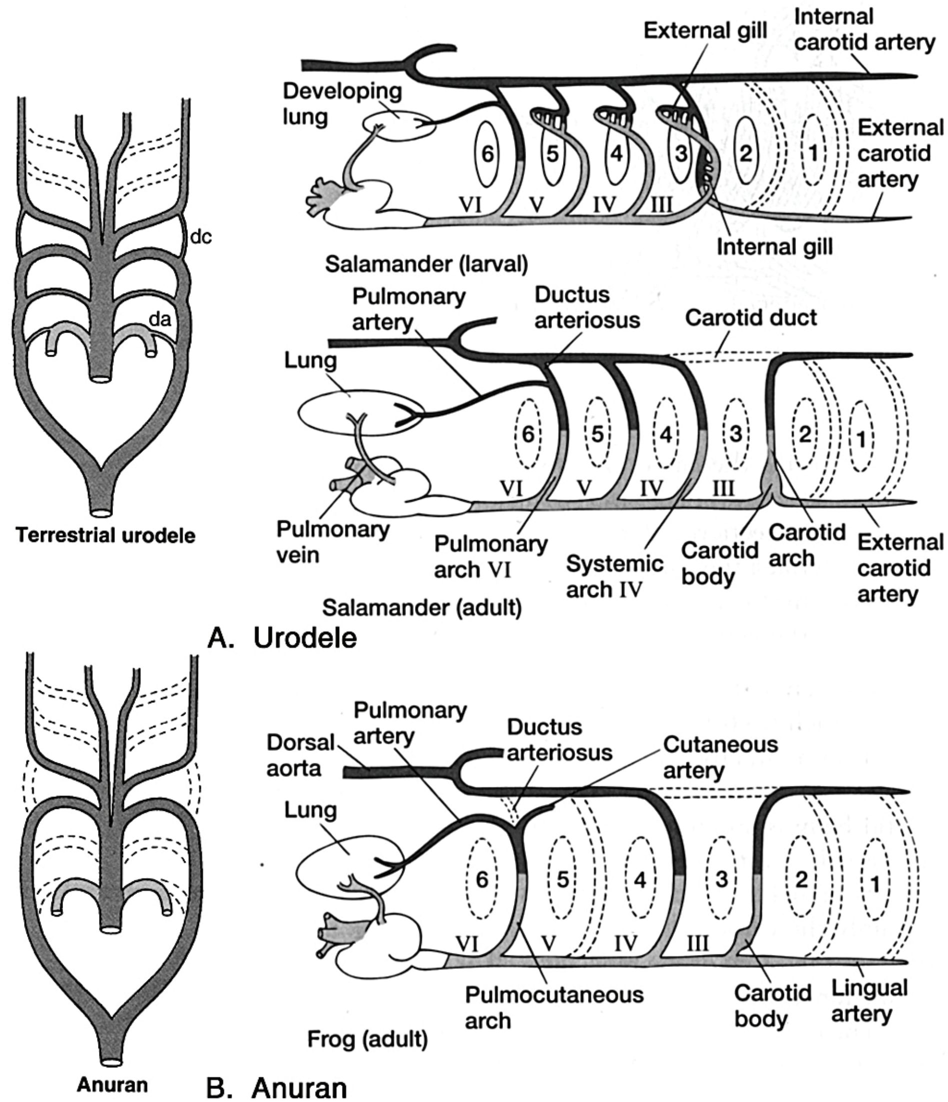


FIGURE 92. **Aortic arch derivatives of Salamanders and Frogs.** **A.** Ventral and lateral aspects of the basic six-arch pattern in a urodele. Ventral and lateral arotic arch systems of terrestrial, adult salamanders at left, bottom. Lateral aortic arch system of an aqautic larval salamander at top. **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, dusctus caroticus.*

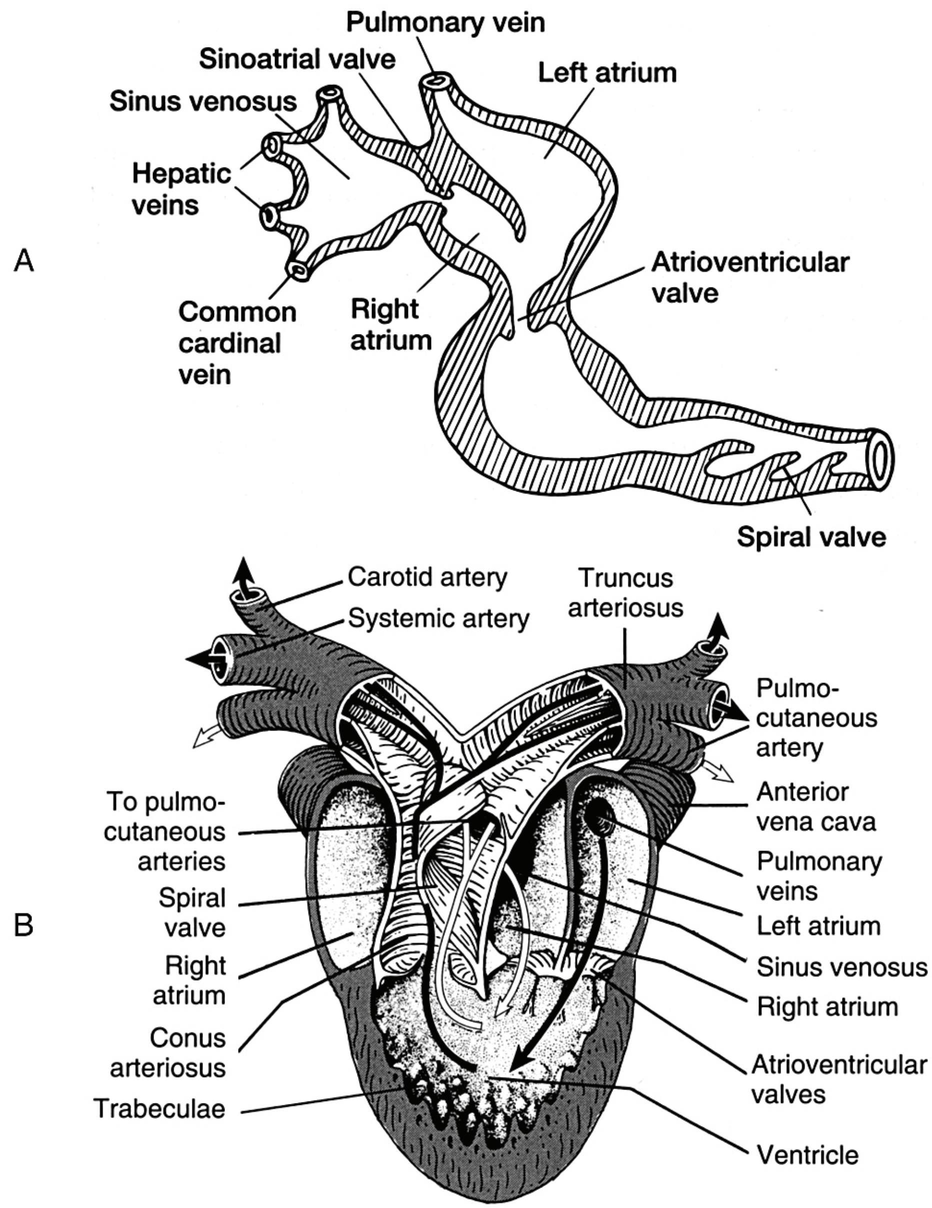


FIGURE 93. **Amphibian hearts. A.** Diagram of a typical amphibian heart. Notice that the atrium is divided into left and right chambers but the ventricle lacks an internal septum. **B.** Heart of *Rana catesbeiana*, the bullfrog. Notice the small ventricular folds or trabeculae. With the aid of the spiral valve, these folds aid in separating systemic and pulmonary bloodstreams 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.

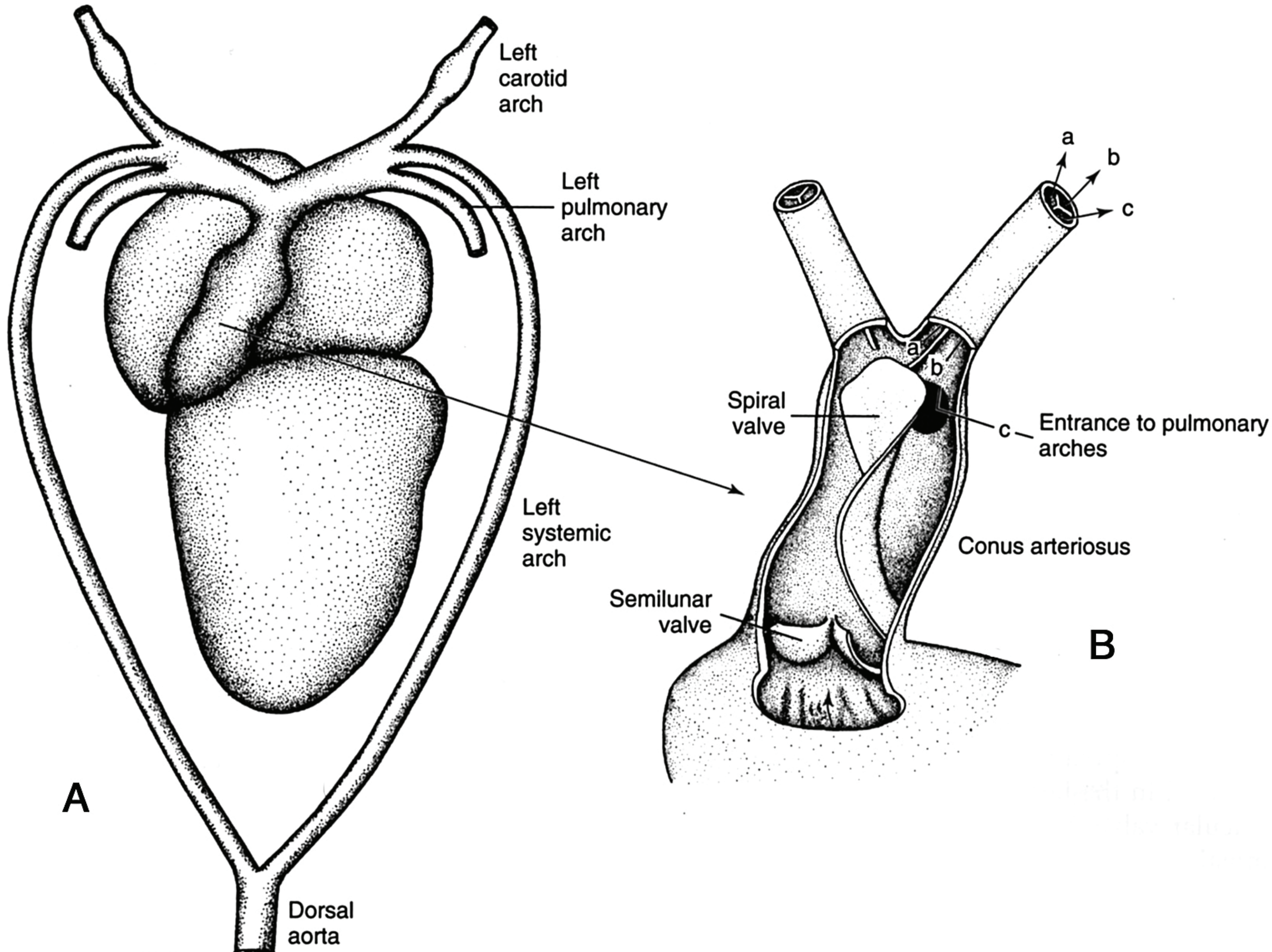
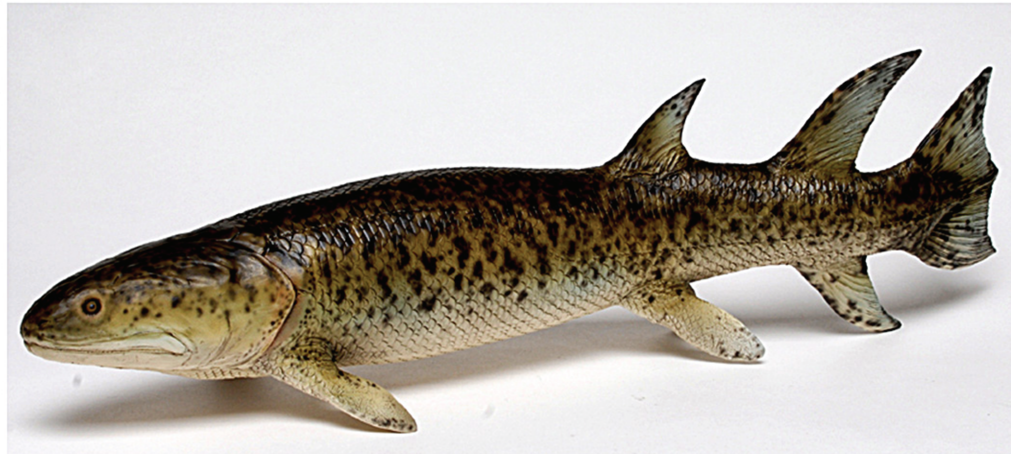


FIGURE 94. **Heart and aortic arches of frog, ventral view. A.** *In situ* aspect of heart and supporting arterial network. **B.** Detail of conus arteriosus opened to show spiral valve and passageways to left carotid arch (**arrow a-a**) and left systemic arch (**arrow b-b**). **Arrow c** enters common passageway to left and right pulmonary arches, then turns to enter passageway to left pulmonary arch.

Eusthenopteron (Rhipidistian)



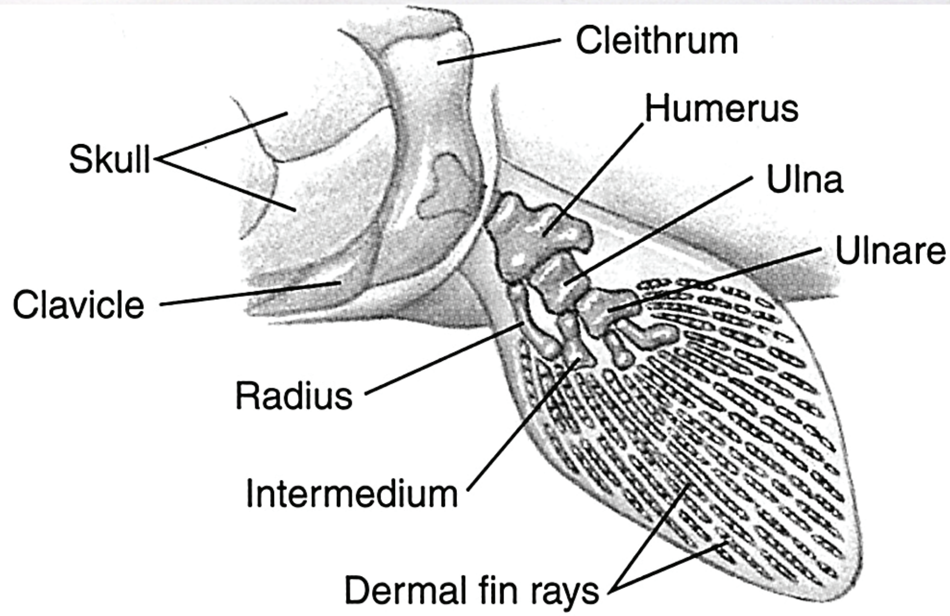


FIGURE 95. Lobe-finned limbs of the late Devonian Rhipidistian *Eusthenopteron*. Legs of modern tetrapods evolved from similar fins in Paleozoic fishes. In *Eusthenopteron*, The anterior fin contained an upper arm bone (humerus) two forearm bones (radius and ulna), and a series of smaller elements (Intermdium 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.

Acanthostega (Ichthyostegalia)

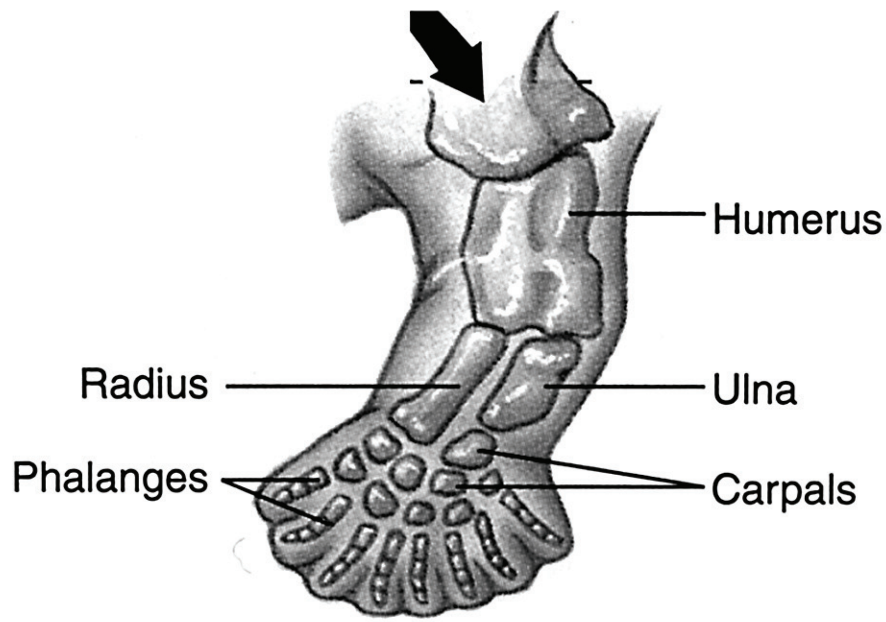


FIGURE 96. **Early tetrapod limb of the early Devonian (360 MYA) ichthyostegalid amphibian *Acanthostega.*** The ulnare and intermedium of the rhipidistians has been replaced by a true carpal series to form a modern wrist. The dermal fin rays of the rhipidistian model have been replaced by eight fully evolved fingers or phalanges. The pectoral girdle includes typical tetrapod scapula and clavical elementsand 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)

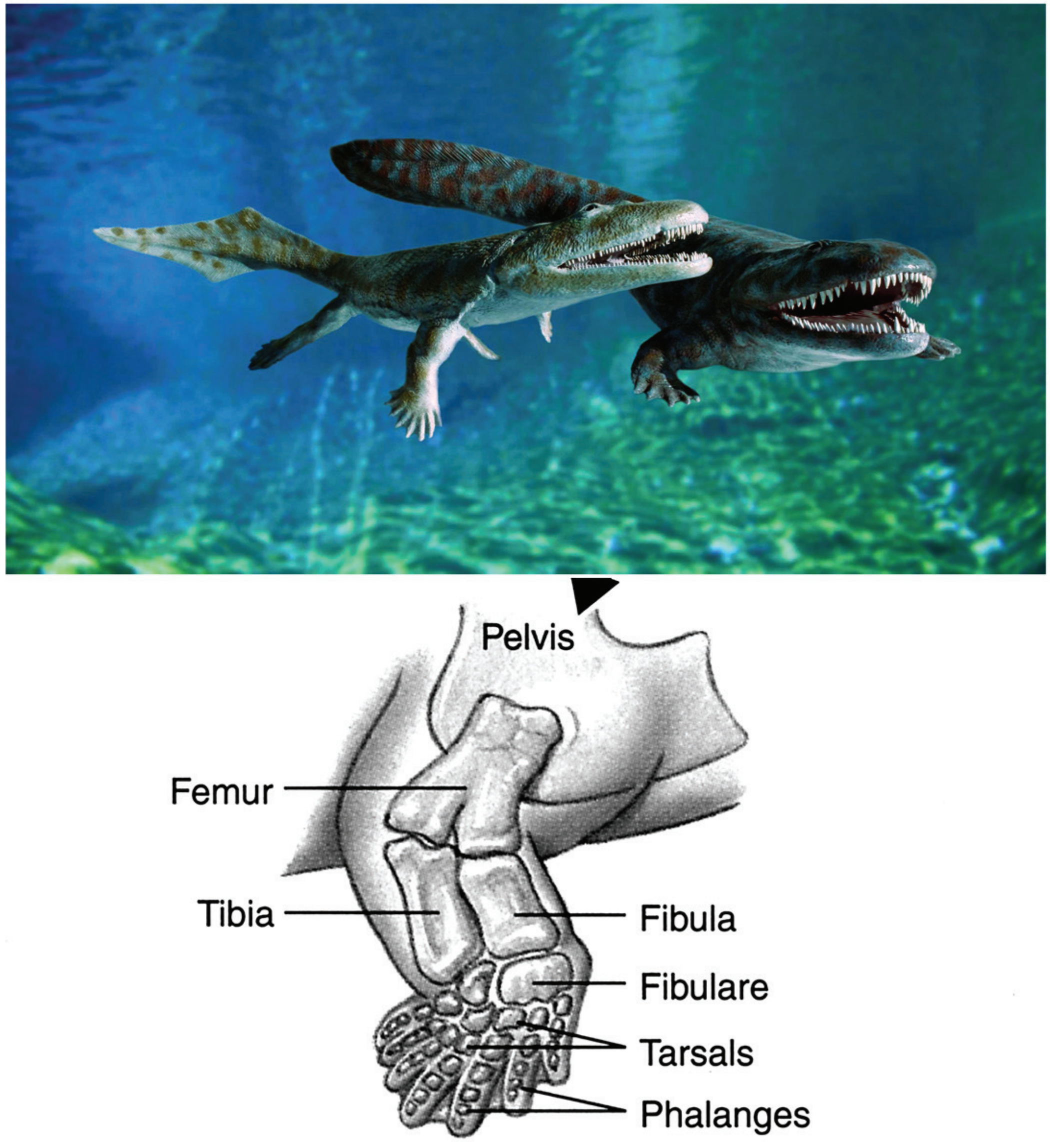


FIGURE 97. Early tetrapod limb of the early Devonian (350 MYA) ichthyostegalid *Ichthyostega*. Girdle and limb structure in *Ichthyostega* is similar to that of *Acanthostega* except that the structure is more fully developed and provides a great deal more support and power for travel on land, thus *Ichthyostega* was probably able to walk on land altough 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.

Limnoscelis (Anthracosauria)

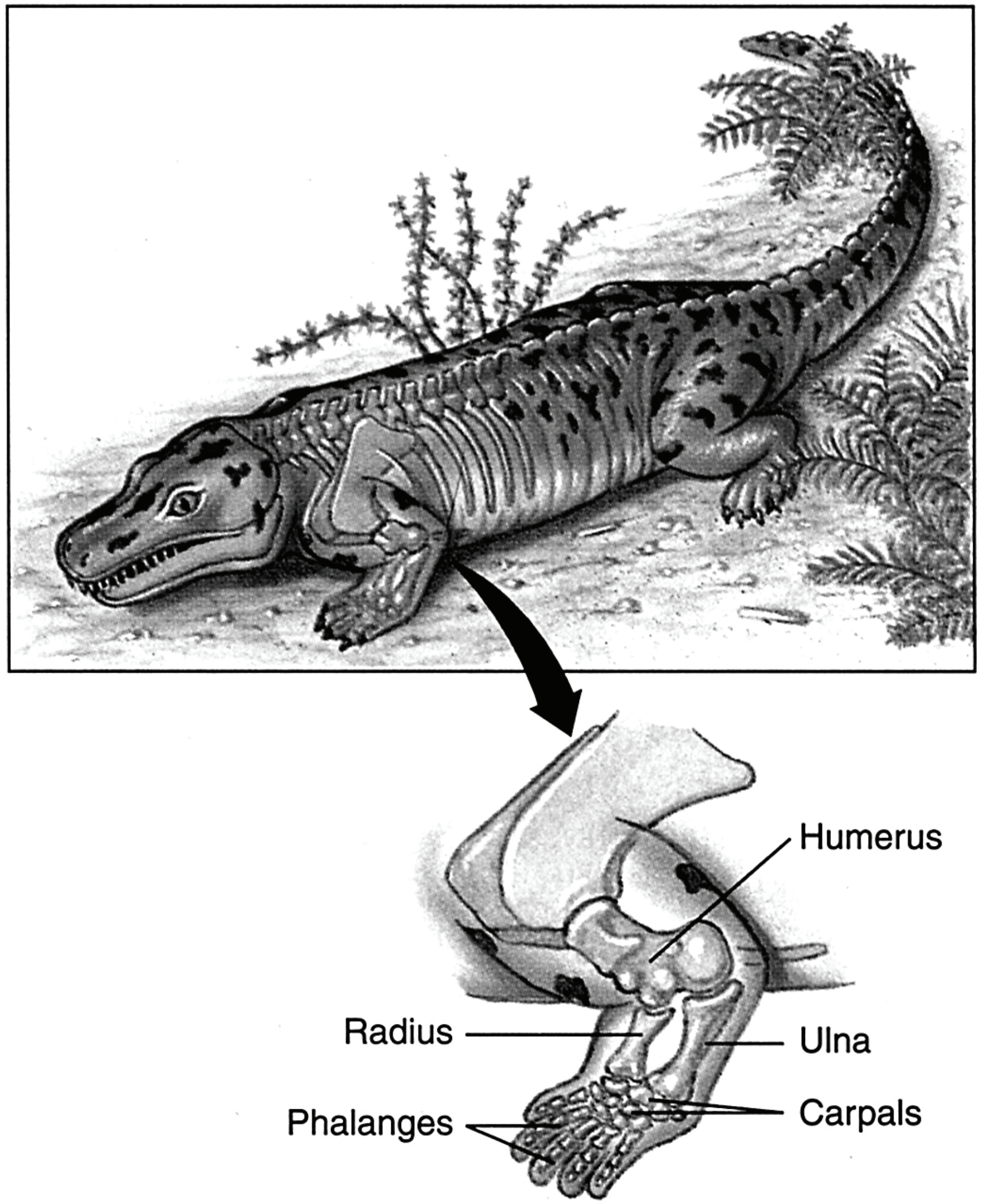


FIGURE 98. Early pentadactylous tetrapod limb of the Carboniferous (300 MYA) anthracosaurian amphibian *Limnoscelis*. The anthracosaurians display full development of the pentadactyl tetrapod limb model that persists as the terapod standard. A developed, independent girdle system, single upper and paired lower limb long bones, carpal-based wrists and fully developed phalanges that are fixed at 5-digits per limb: the pentadactyl standard.

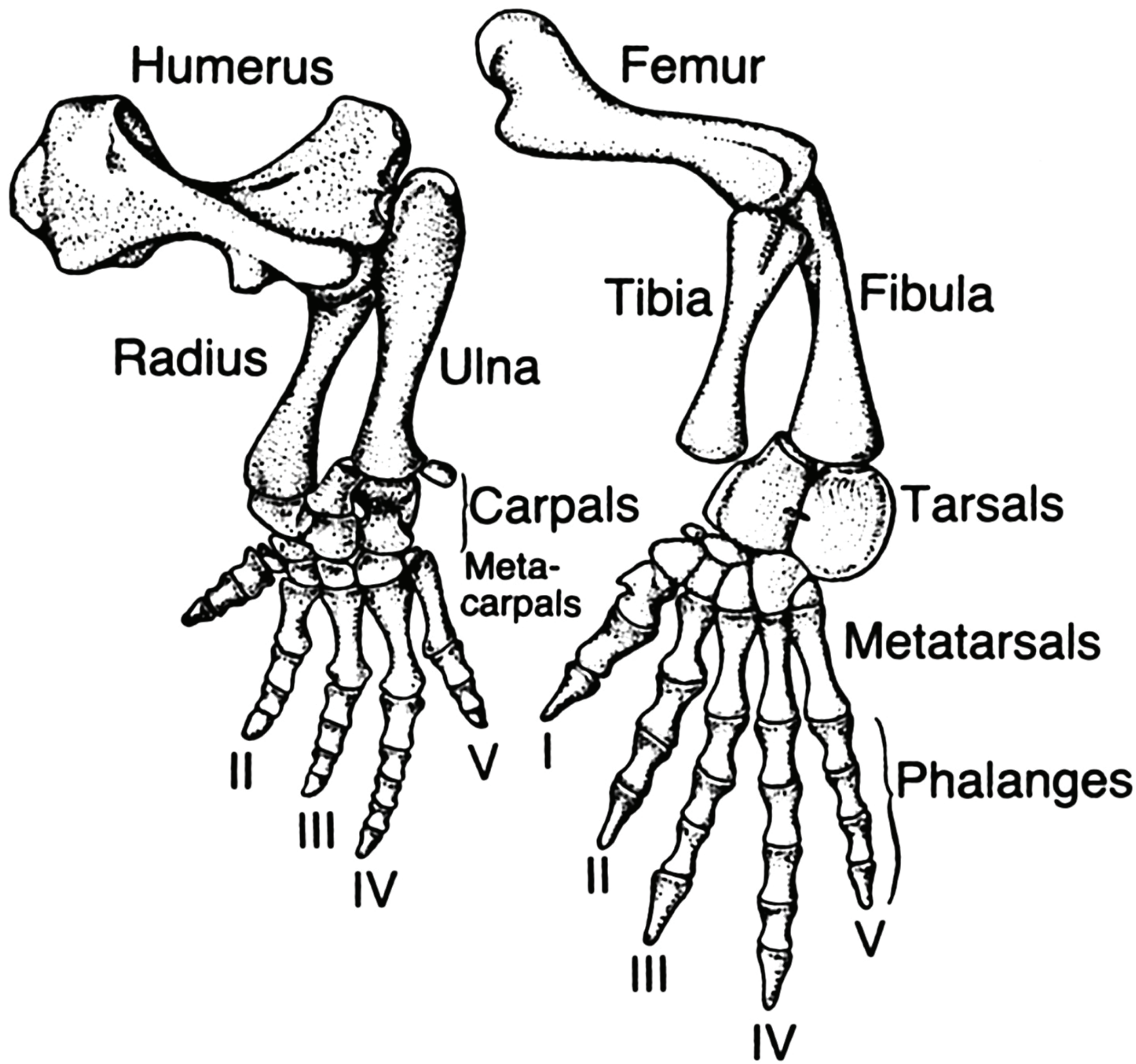


FIGURE 99. **General pattern of the modern pentadactylous tetrapod limb: left front (*left*) and hind (*right*) limbs of a primitive reptile *Ophiacodon*.** Roman numerals indicate digits. (*after Romer*)

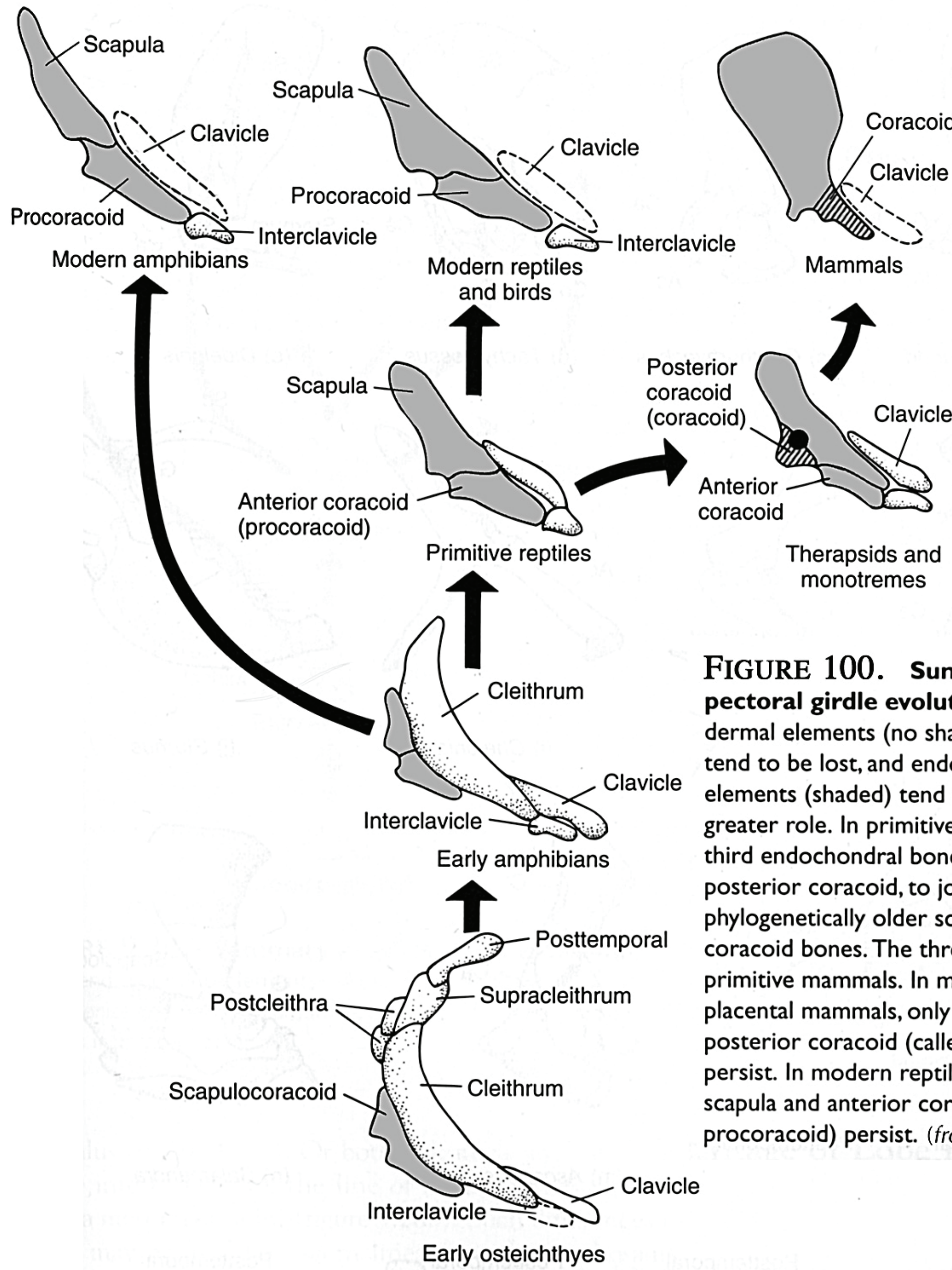


FIGURE 100. **Summary of pectoral girdle evolution.** Notice that dermal elements (no shading) of the girdle tend to be lost, and endochondral elements (shaded) tend to assume a greater role. In primitive therapsids, a third endochondral bone appears, the posterior coracoid, to join with the phylogenetically 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*)

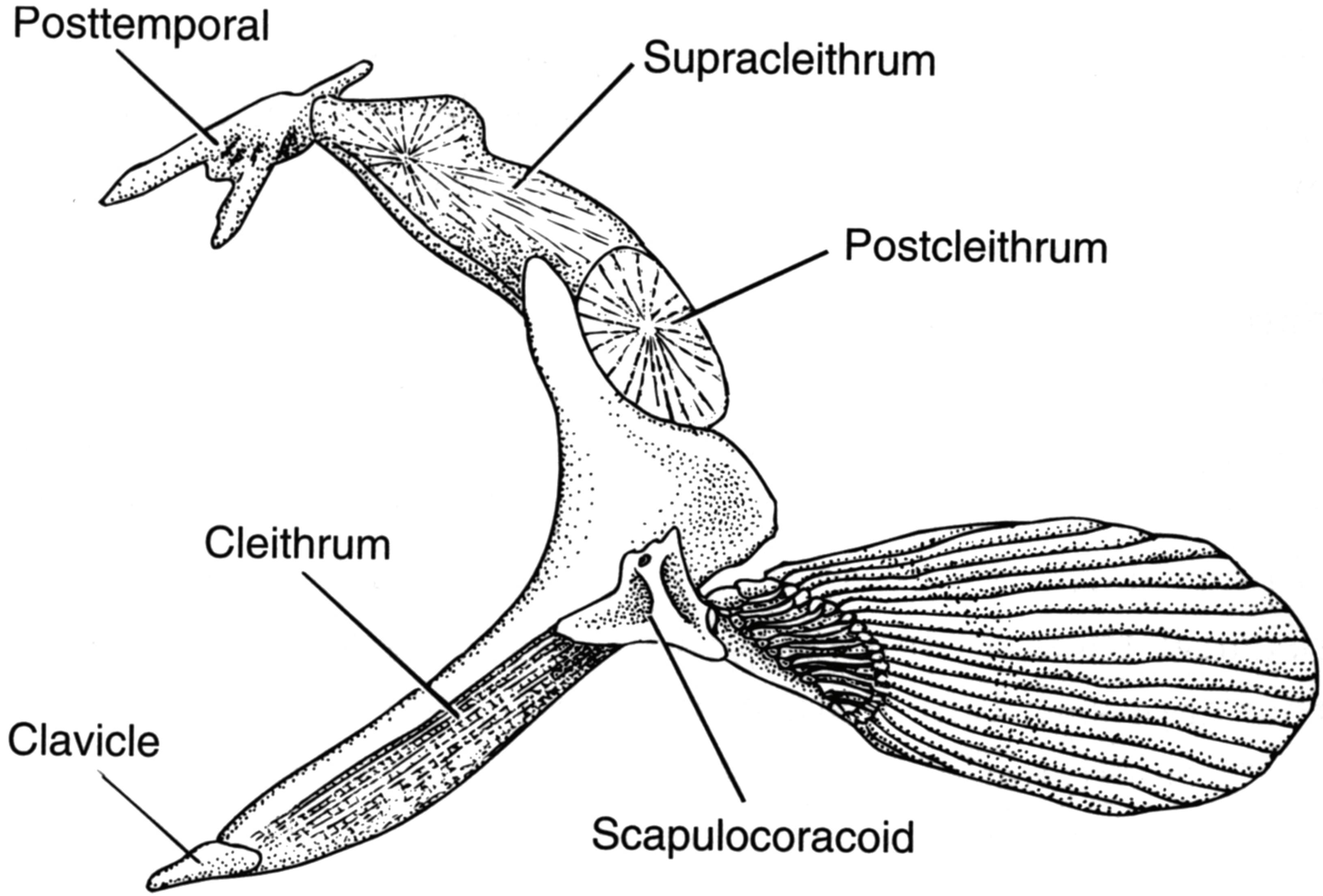


FIGURE 101. Pectoral girdle of *Amia*, a primitive actinopterygian. Note supracleithrum and its connection to the posttemporal bone. This articulation joins the pectoral girdle to the rear of the skull and is the typical arrangement in fish. (*from Kardong*).

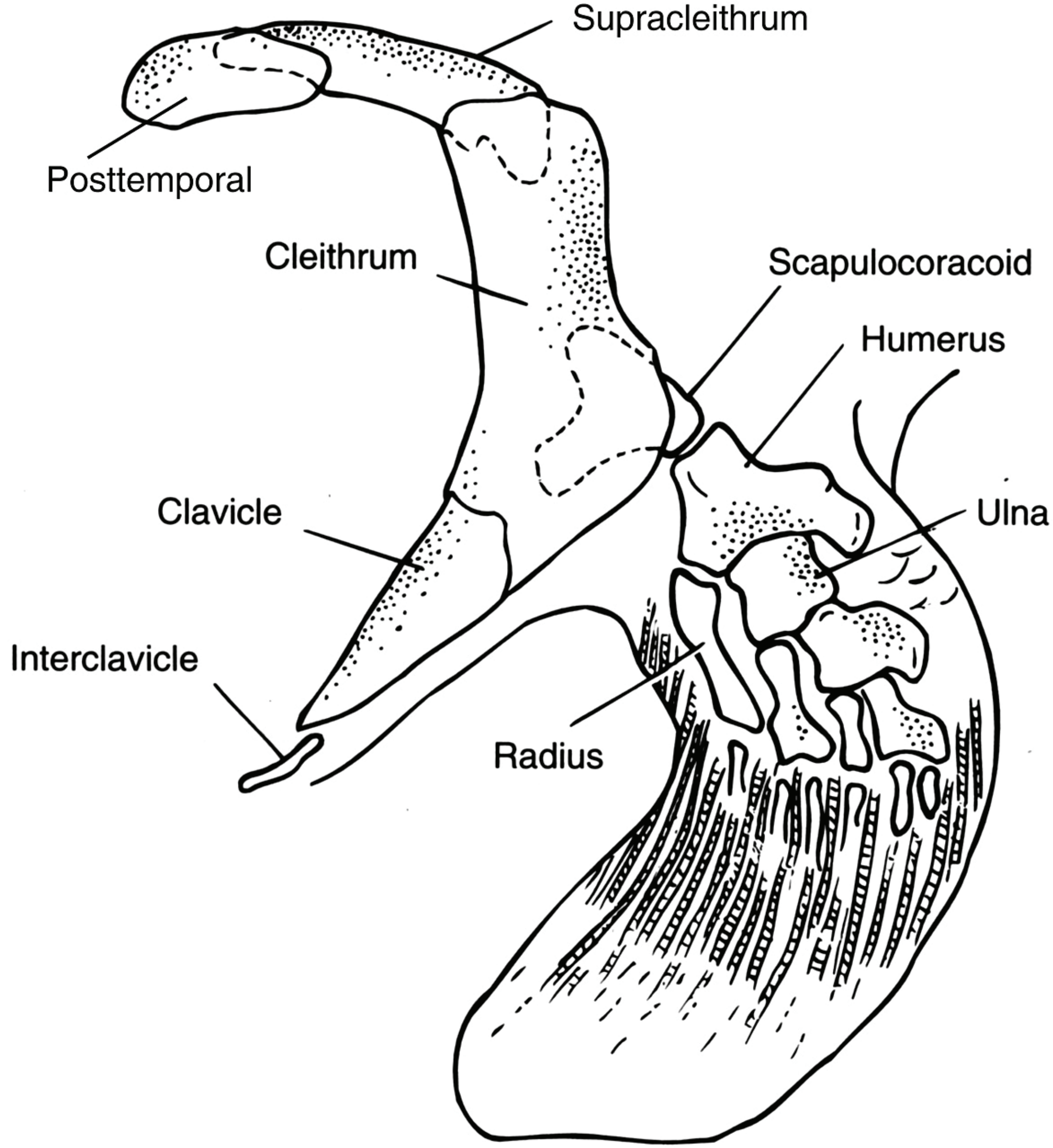


FIGURE 102. Appendicular skeleton of *Eustenopteron*, a crossopterygian from the late Devonian. Note supracleithrum and its connection to the posttemporal bone observed in actinopterygians remains apparent, joining the pectoral girdle to the rear of the skull. Also note the scapulocoracoid. It is small and serves to ariculate the humerus thus it is both homologous and analagous to the scapulocoracoid in other fishes. (*After Romer, Jarvik*).

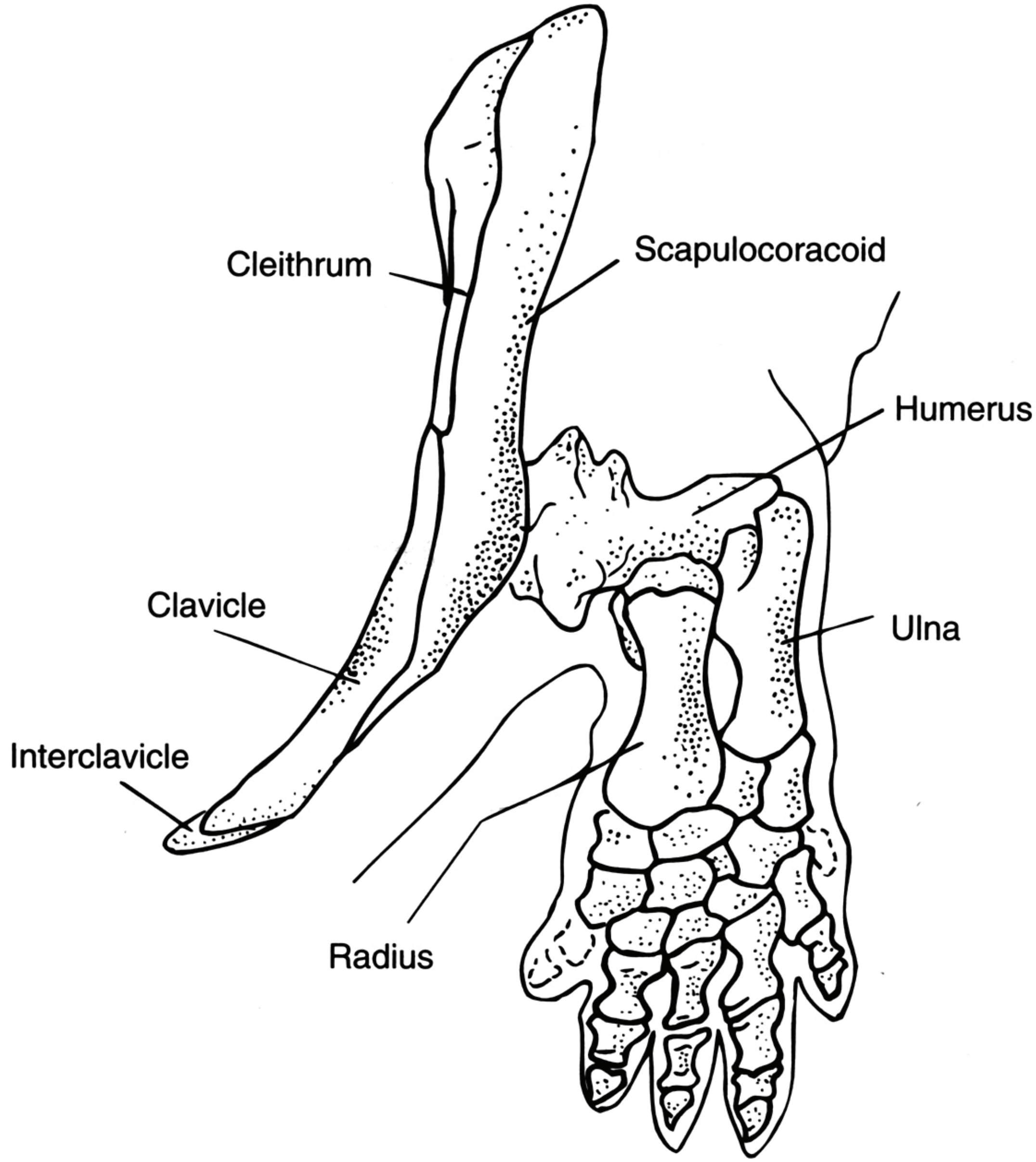


FIGURE 103. Appendicular skeleton of *Eryops*, a labyrinthodont (temnospondylid) amphibian from the Carboniferous. The supracleithrum has been lost, freeing the pectoral girdle from its connection to the rear of the skull. Note the increased size and prominence of the scapulocoracoid as it enlarges it will evolutionarily give rise to the prominent scapulae of later tetrapods. The cleithrum, clavicle and interclavicle have begun to shift ventrally to form the ventral yoke of the pectoral girdle. (*After Romer, Jarvik*).

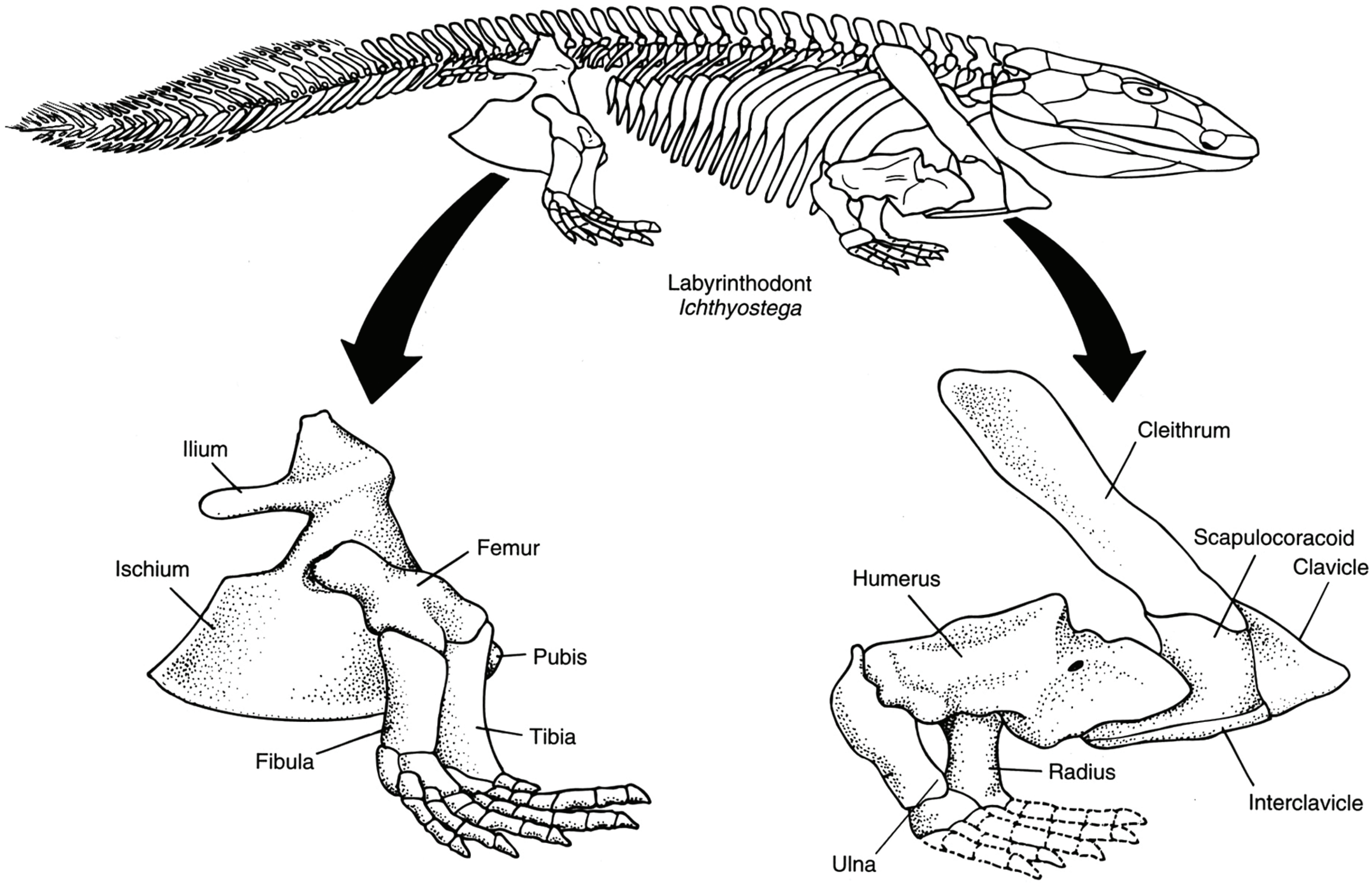


FIGURE 104. Appendicular skeleton of *Ichthyostega,* an Devonian ichthyostegalid labyrinthodont amphibian. The number fo digits carried on the forelimb is not known, but seven digits were present on the hindlimb. The supracleithrum and its connection to the posttemporal bone and skull are lost. A primitve tetrapod pectoral girdle consisting of scapulocoracoid, cleithrum, clavicle and interclavicle is well-developed. (*after Jarvik*).

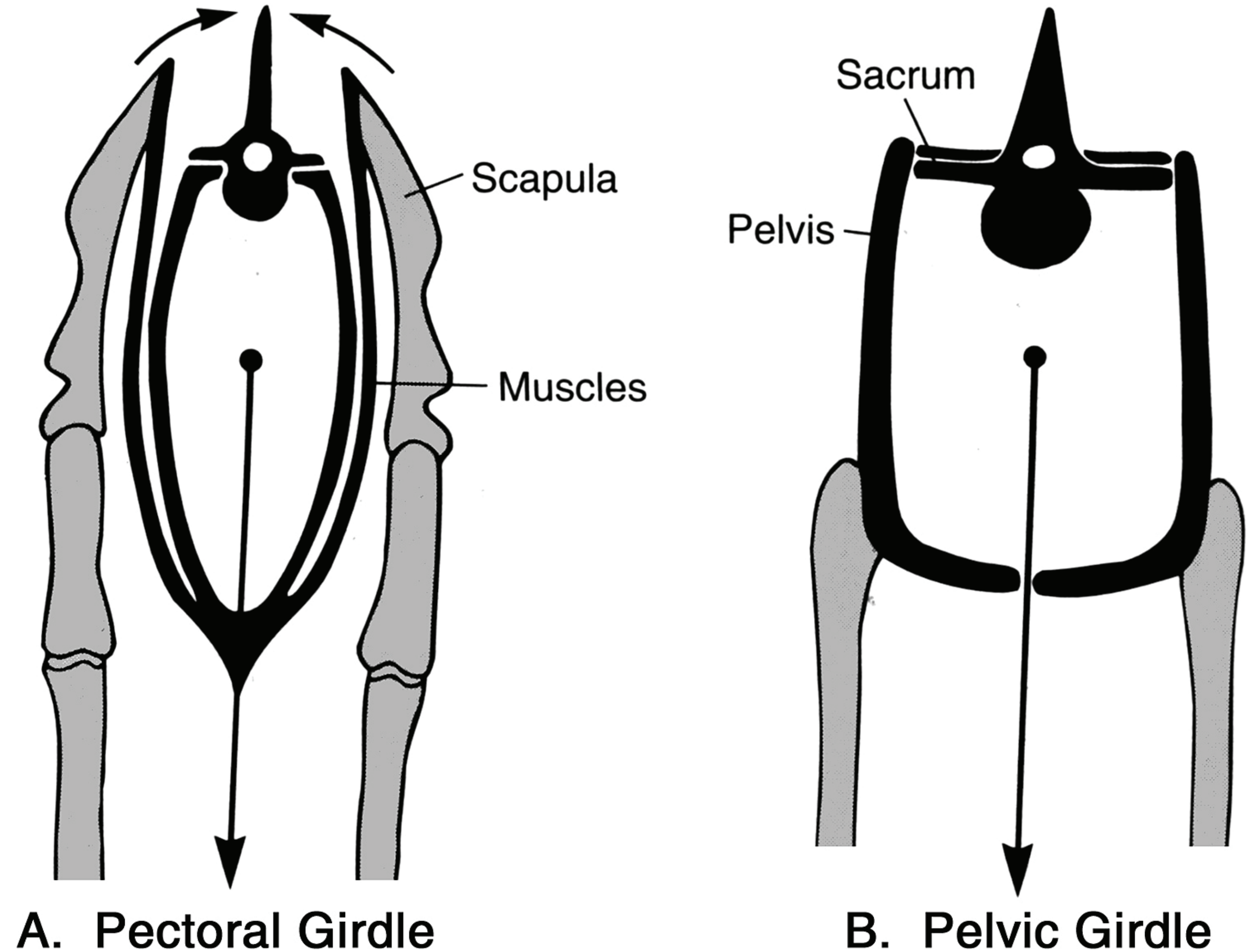


FIGURE 105. Comparative functional morphology of appendicular girdles in tetrapods. **A.** The pectoral girdle is not attached directly to the vertebral column, thus the muscles of the pectoral girdle support the anterior part of the tetrapod body in a musclular sling. The relative position of the limb determines the *direction* of force transfer in the body. In this example, the legs are positioned directly below the body. Most of the force is transmitted to the muscular sling. Force vectors driving the upper limbs together dorsally are reduced. **B.** The pelvic girdle is attached directly to the vertebral column via the sacrum. (*from Kardong*)

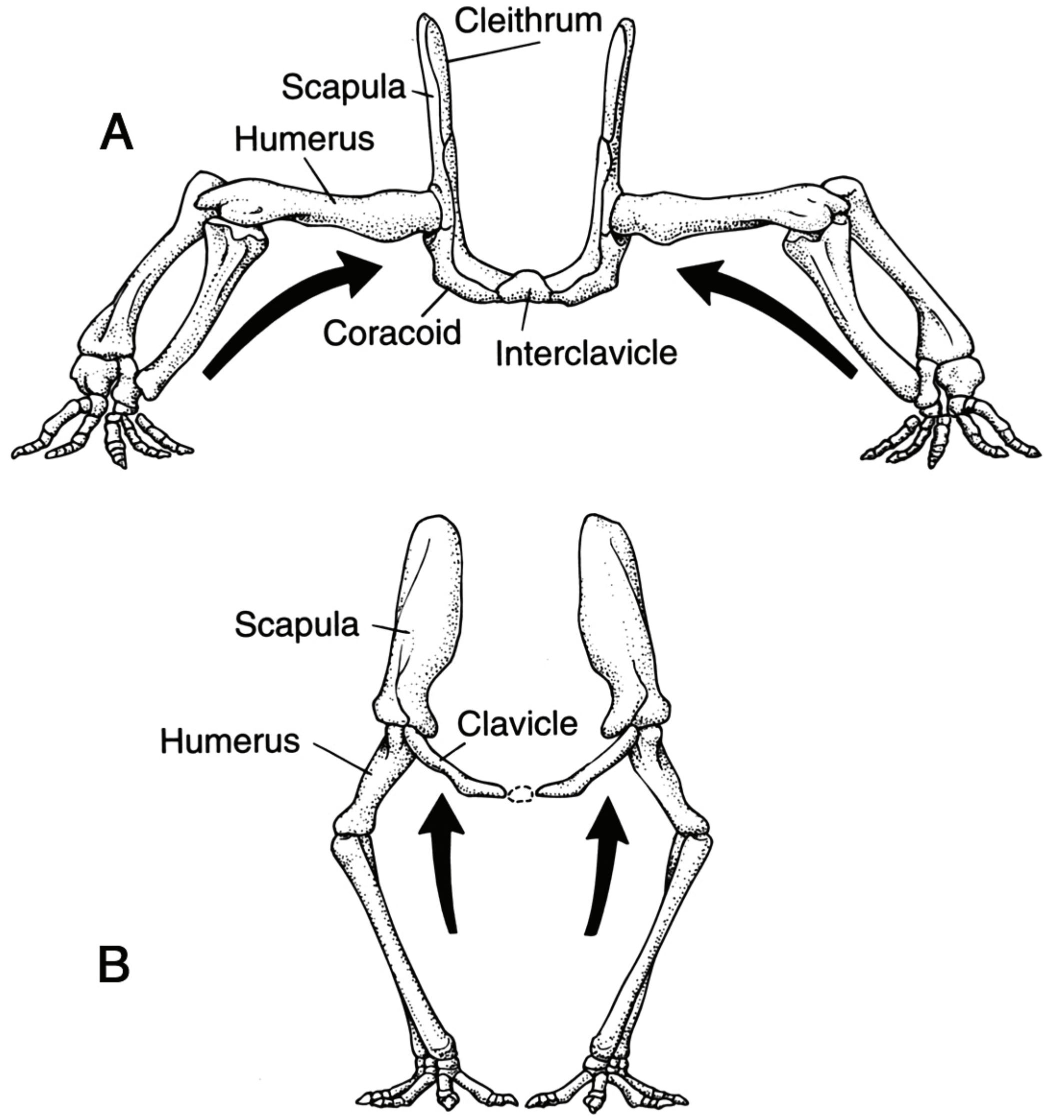
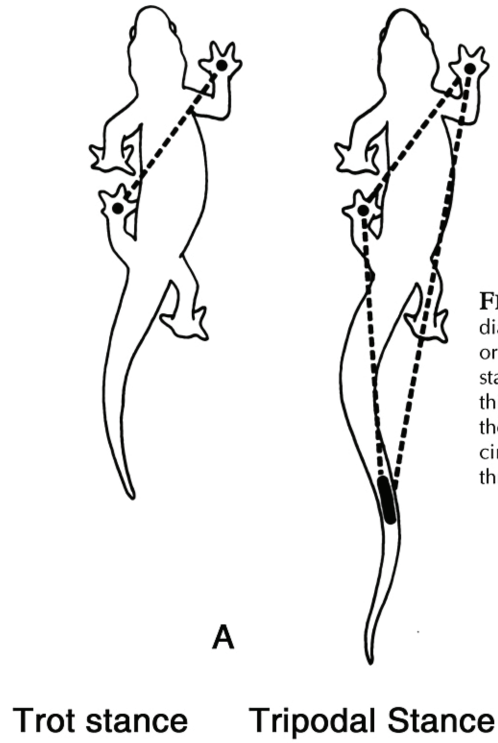


FIGURE 106. Changes in the role of the pectoral girdle with changes in limb posture.
A. Sprawled posture directs most of the force medially to the pectoral girdle. The medial elements of the pectoral girdle assume a major role in resisting this compressing force. Thus the interclavicle and coracoid are enlarged and strengthened to maintain the girdle.
B. As limbs are brought under the body, these forces are directly less toward the midline and more in a vertical direction: the lateral compressing force is thus transformed into a vertical force onthe muscular pectoral sling. In evolutionary lines that have shifted limb posture there is a pronounced loss or reduction of medial pectoral elements and a corresponding increase in lateral elements such as the scapula. (*from Kardong*)



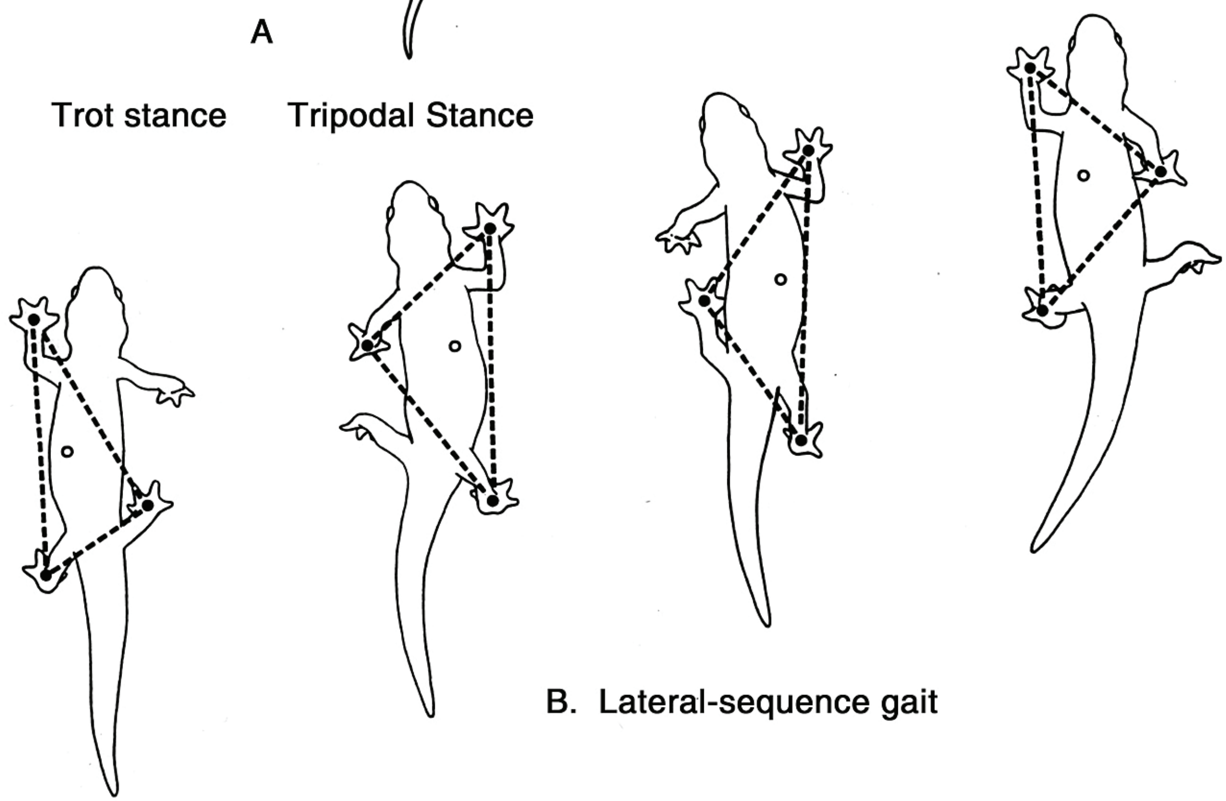


FIGURE 107. **Primitive gaits. A.** Locomotor stability. During the trot (left) diagonally opposite feet meet the ground together. The center of mass lies on or near the line connectingthese two points of support. The same walking stance is stabilized (tripodal gait, right) by adding a third point of support. In this case the tail is pressed to the ground to form a triangular support around the center of mass. **B.** In the lateral-sequence gait the center of mass (open circle) never leaves the triangle of support established by a gait cycle of three of the four limbs. (*from Kardong*)

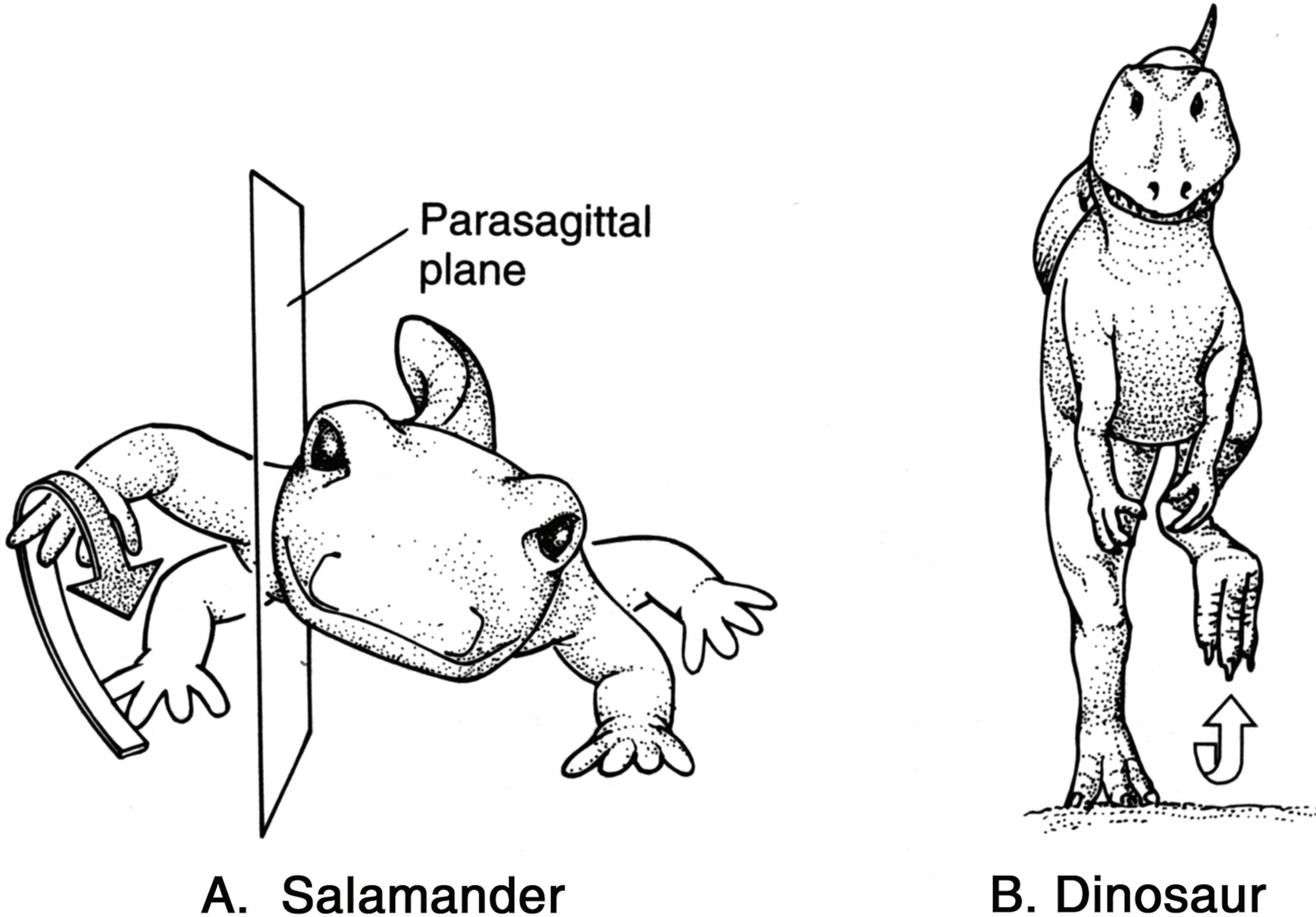


FIGURE 108. Role of limb rotation in terrestrial locomotion. A. Terrestrial but noncursorial salamanders acheive limb recovery by an overhand swing of the arm outside the parasagittal plane. **B.** Cursorial animals such as dinosaurs acheive limb recovery by a pendulum-like swing in the parasagittal plane. This keeps the limbs directly below the body to support body weight. The pendulum-like swing improves the ease, efficiency, and speed of limb recovery. (*from Kardong*)

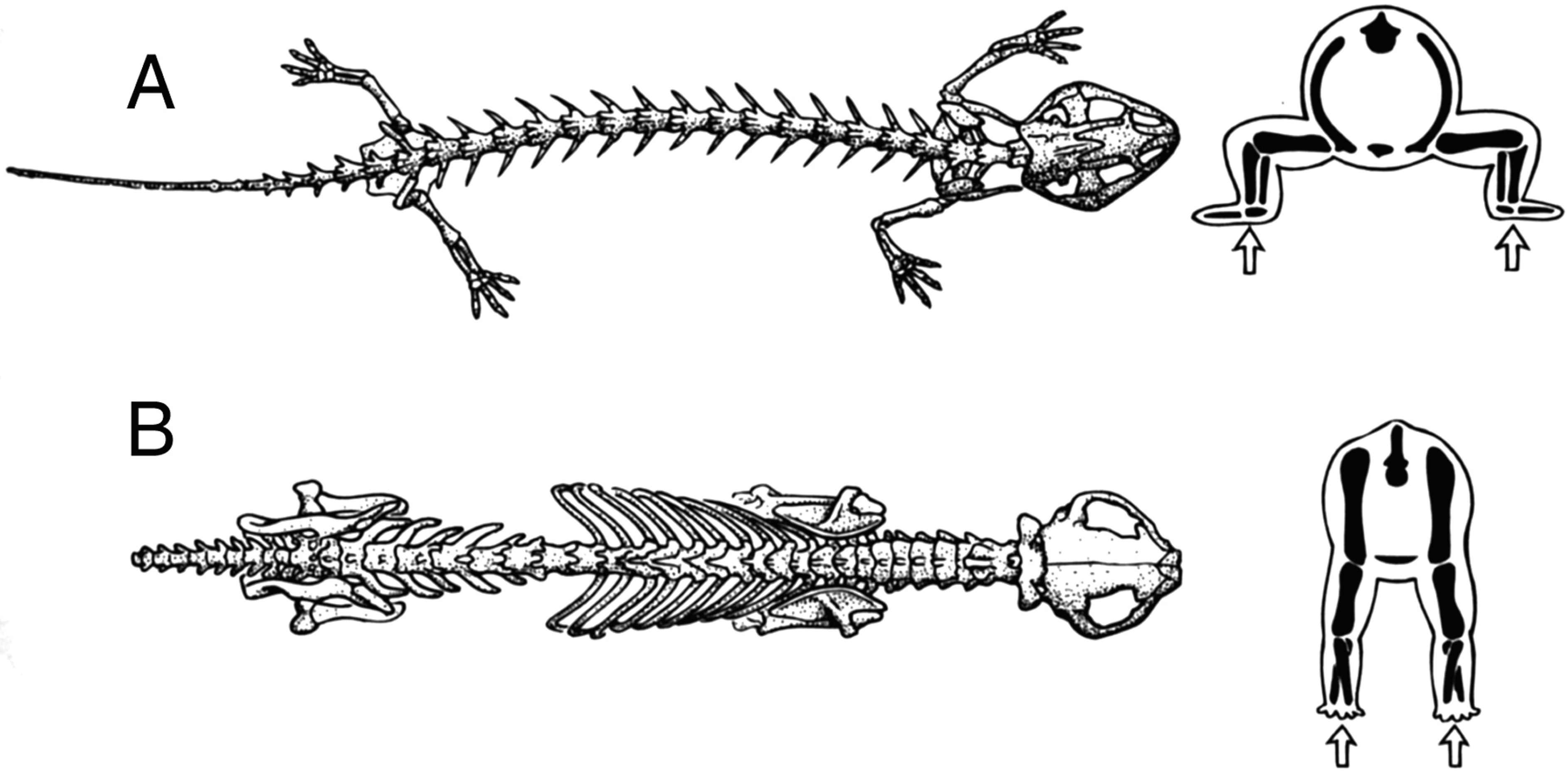


FIGURE 109. Changes in limb posture and terrestrial locomotion. A. The sprawled posture exhibited by a salamander was typical of fossil amphibians as well as of most reptiles. **B.** The posture exhibited by placental mammals appear in an early form in synapsid reptiles. Later reptile lineages carried the limbs under the body, dramatically increasing the efficiency of rapid terrestrial locomotion. Note the concommitant reduction in spinal flexure. (*after Kardong*)

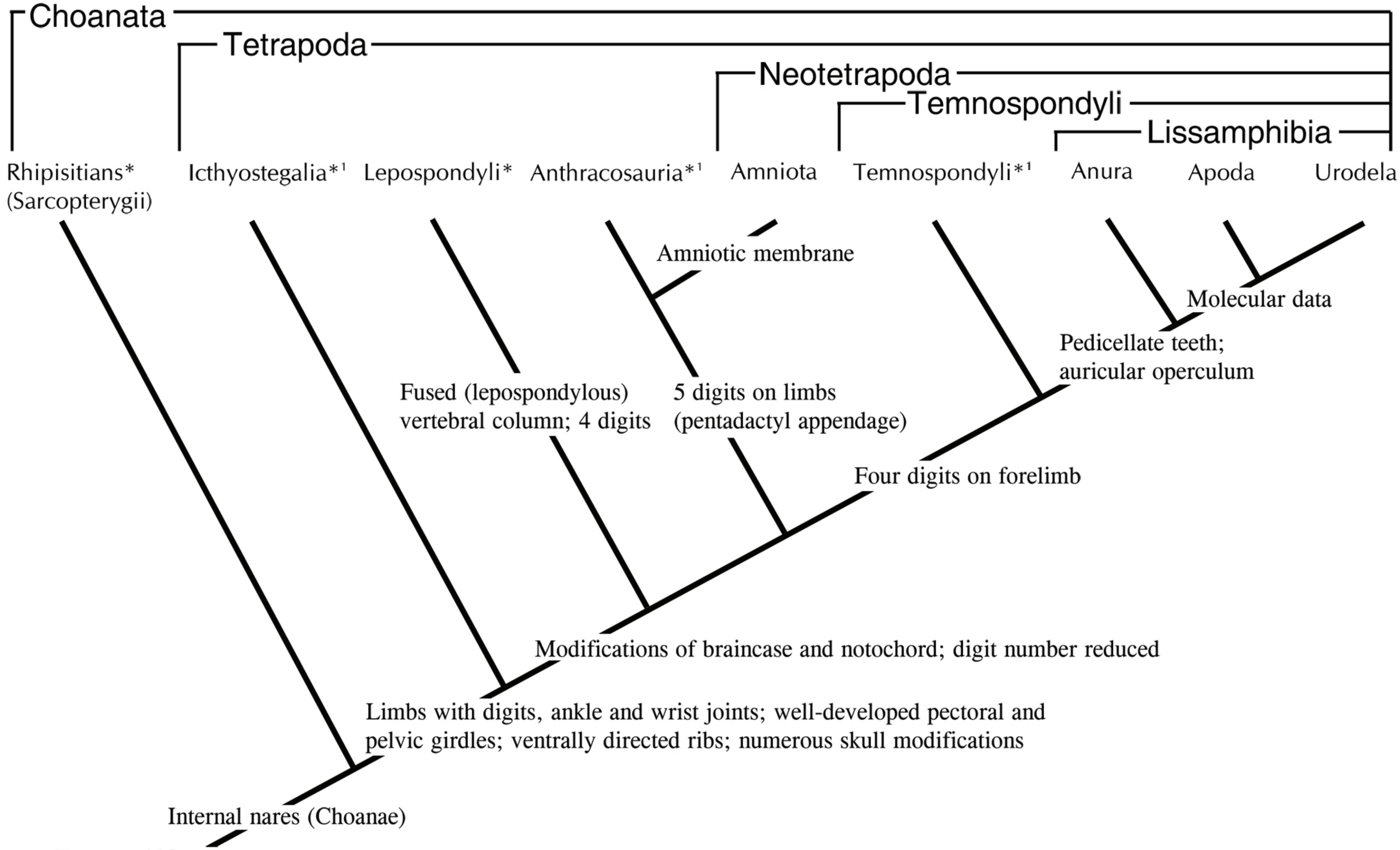


FIGURE 110. Cladogram of the Amphibians. The arrangement presented above assumes monophyly of the Lissamphibia and polyphyly among the Labyrinthodontia. Note that this arrangement weights the reduction of digits and utilizes molecular data to maintain monophyly of Lissamphibia. * indicates extinct group; [1] member of the Labyrinthodontia

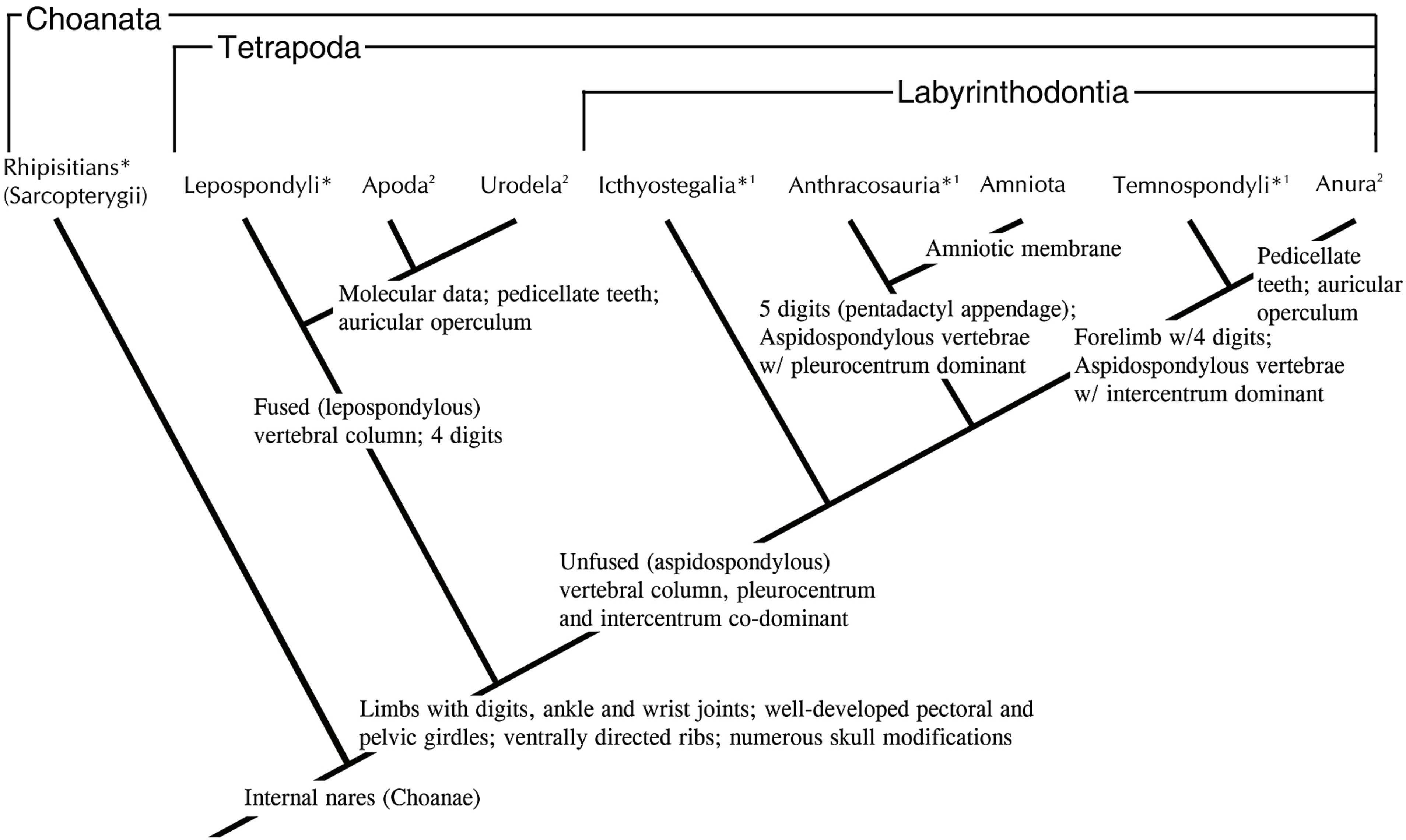


FIGURE 111. Cladogram of the Amphibians. The arrangement presented above assumes monophyly of the Labyrinthodontia and polyphyly among the Lissamphibia. Note that this arrangement weights vertebral characters and fails to preserve monophyly of Lissamphibia.
* indicates extinct group; [1] member of the Labyrinthodontia; [2] member of the Lissamphibia

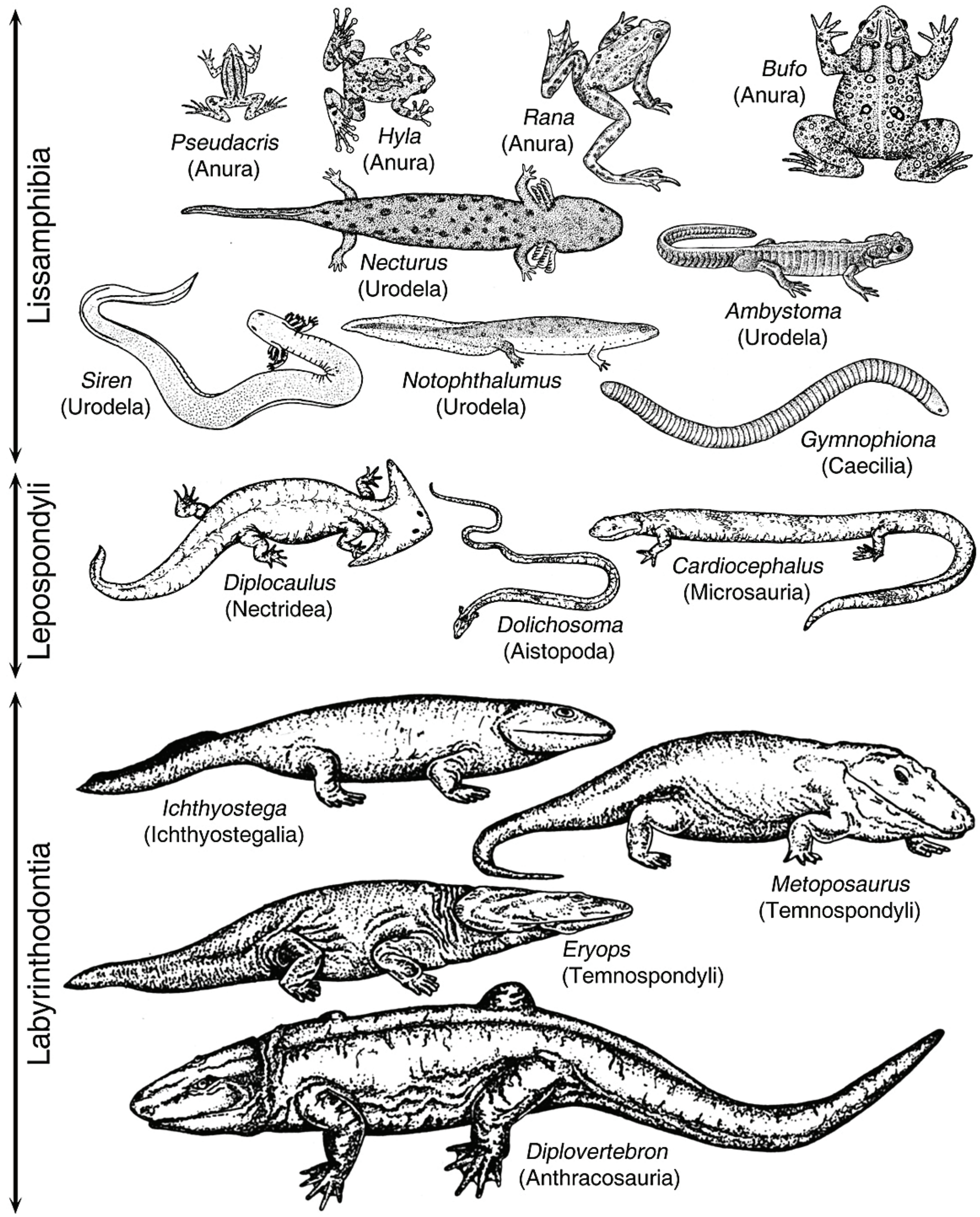


FIGURE 112. Representative diversity of class Amphibia, extinct and extant.

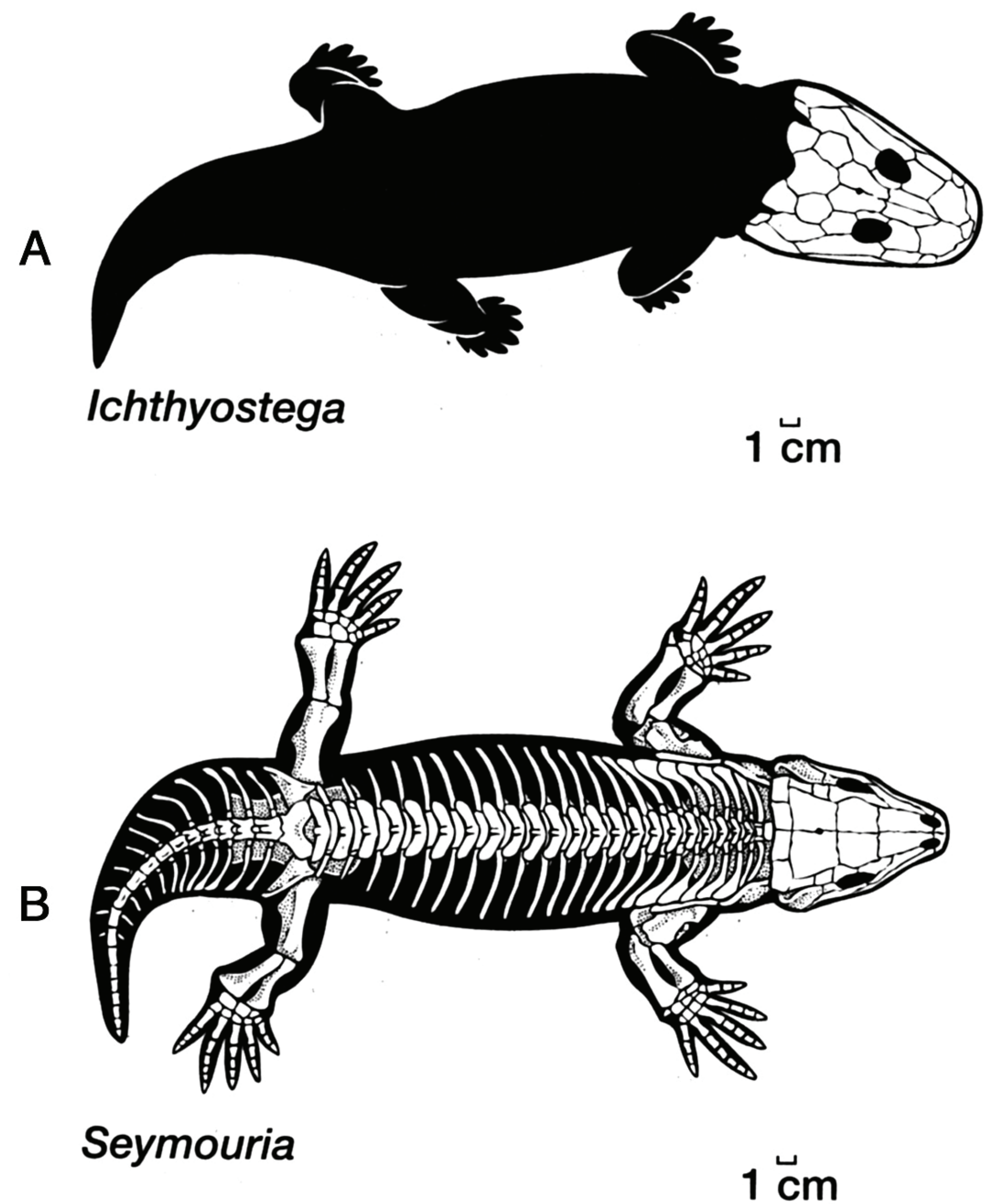


FIGURE 113. **Rhipidistian skull types among representative labyrinthodonts.**
A. *Ichthyostega*, an ichthyostegalian from the late Devonian (ca. 1 m long).
B. *Seymouria*, an anthracosaurian from the early Permian (ca. 50 cm long).
(*from Kardong*)

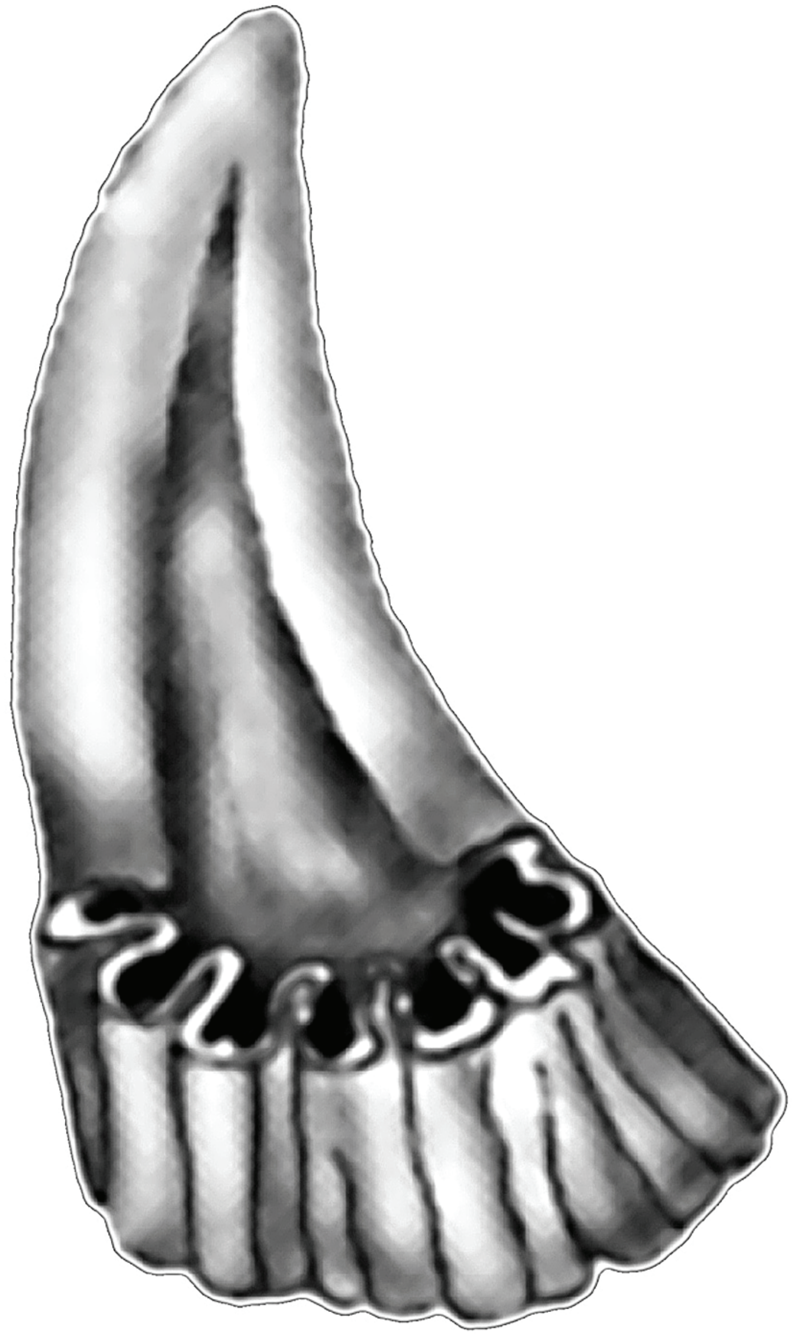
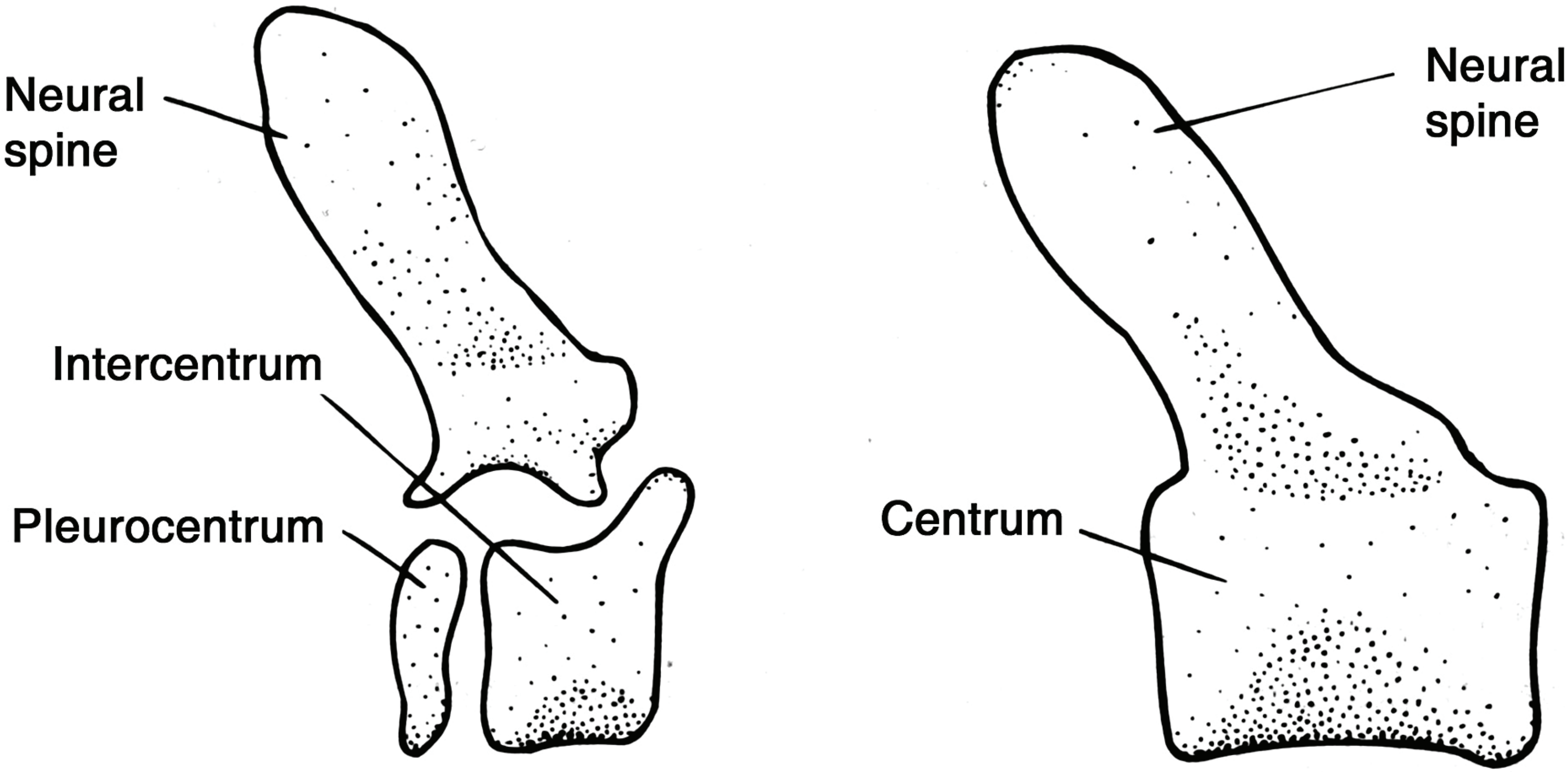


FIGURE 114. Labyrinthodont tooth.



A. Aspidospondylic vertebra

B. Lepospondylic vertebra

FIGURE 115. **General vertebral types. A.** Aspidospondylic vertebrae are characterized by distinctly separated ossified elements. The nerual spine, intercentrum, and pleurocentrum are readily observed in this rhachitomous vertebra but in other types the intercentrum or pleurocentrum may be dominant. **B.** Holospondylic vertebrae are characterized by fusion of all elements to form a solid centrum. (*from Kardong*)

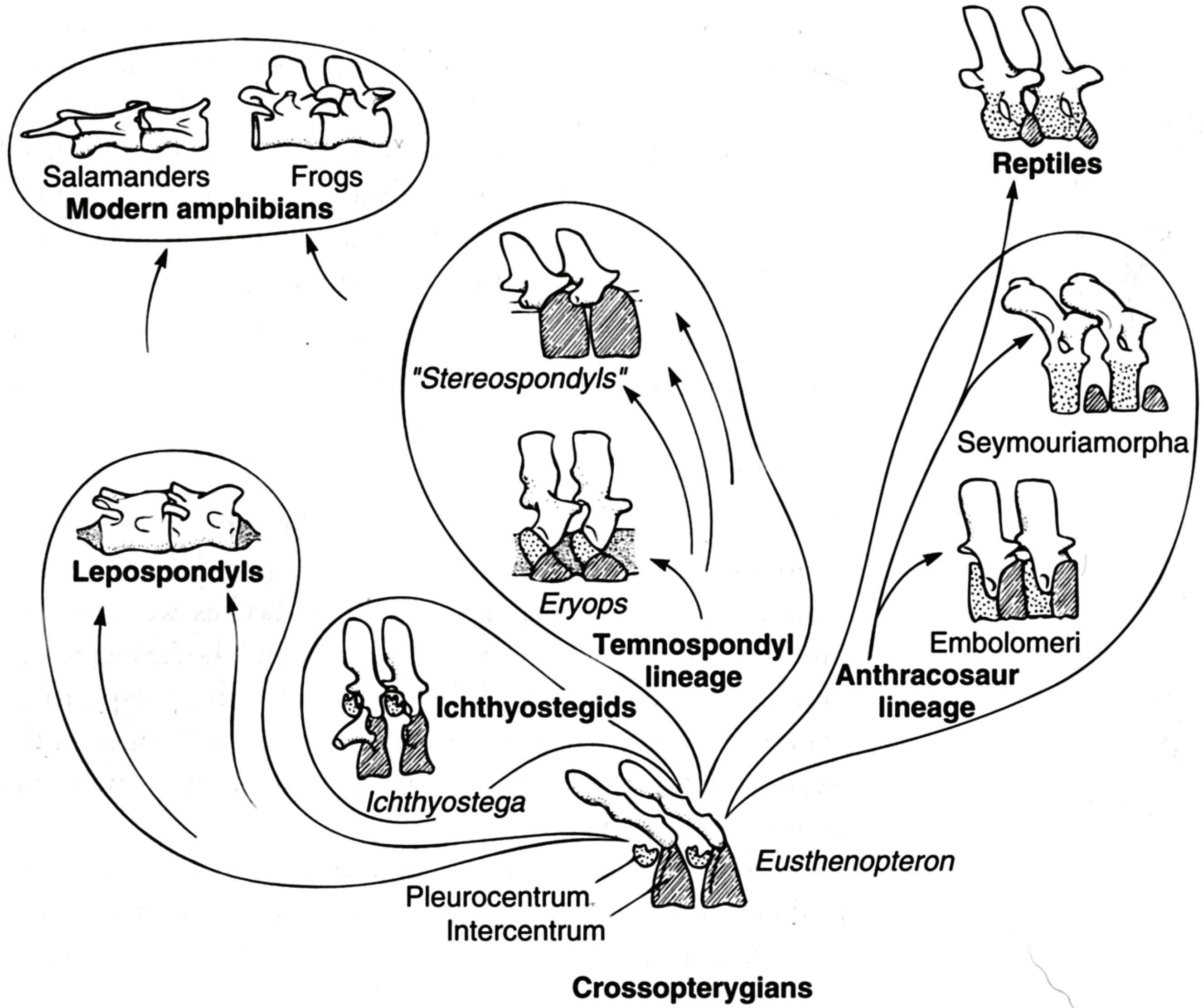


FIGURE 116. Evolution of tetrapod vertebrae. The lepospondyl condition appeared early. It may have given rise to the modern Caedilians and Urodeles or it may have been restricted to an extinct taxon, the Lepospondyls. If this is the case, then the solid verterae of modern amphibians arose independently. The rhachitomous aspidospondylous vertebrae inherited from the Rhipidistians evolved along two major lines. In the temnospondylid line the intercentrum enlarged at the expense of the pleurocentrum. In the anthracosaurian line the pleurocentrum became predominant. Temnospondylids probably gave rise to the Anura and perhaps all of the Lissamphibia. Anthracosaurs gave rise to the Reptiles and other "higher" tetrapods. (*from Kardong*)

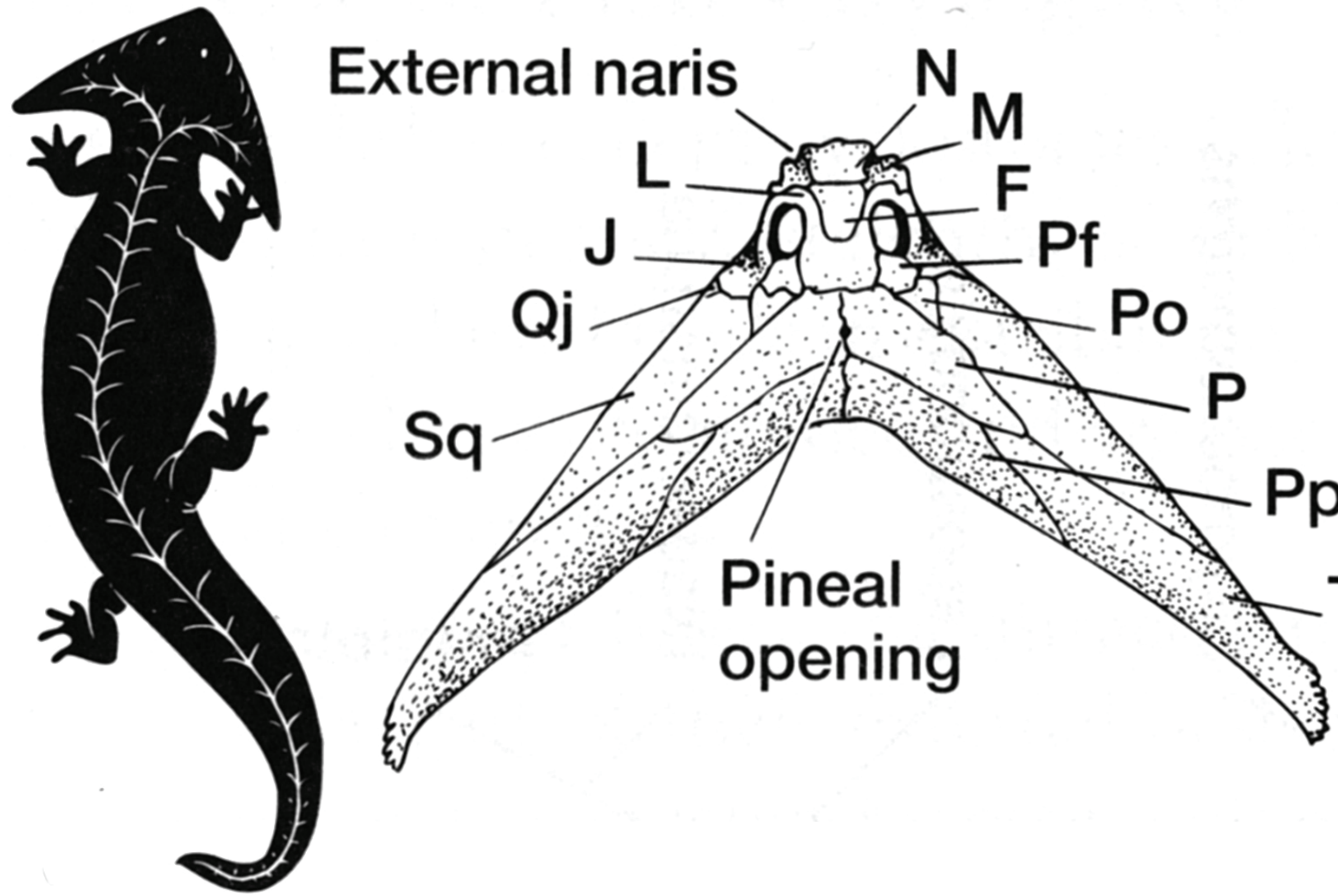


FIGURE 117. ***Diploceraspis,*** **one of the horned nectridians of the early Permian.** This leospondyl amphibian was about 60 cm long. The skull is well developed and is missing no standard Labyrinthodont bone or series. (F, frontal; J, jugal; M, maxilla; N, nasal; P, parietal; Pf, postfrontal; Po, postorbital; Pp, postparietal; Qj, quadratojugal; Sq, squamosal; T, tabular.) (*from Kardong, after Beerbower*)

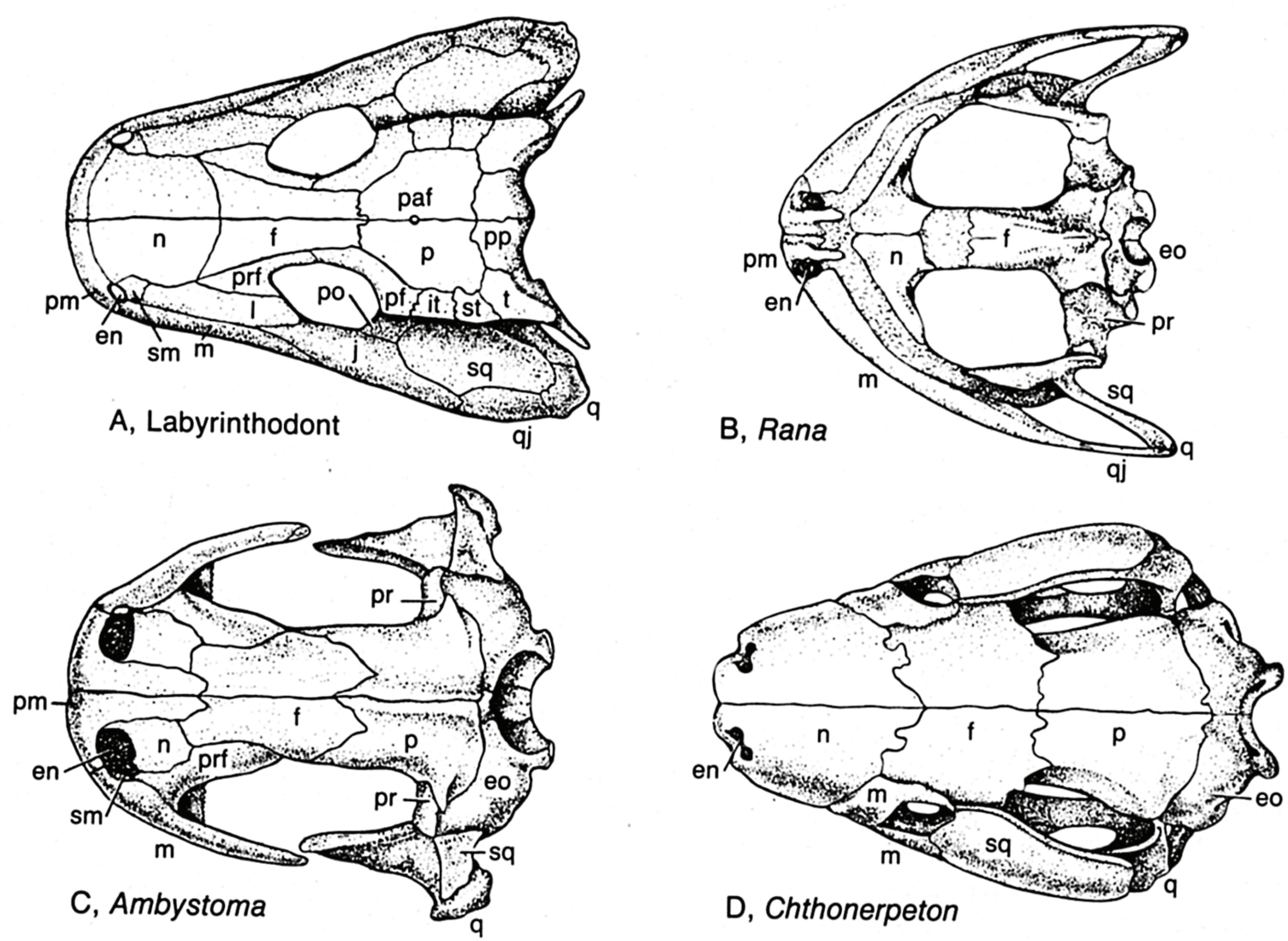


FIGURE 118. Dorsal views of amphibian skulls. A. Primitive labyrinthodont, *Ichthyostega*. **B.** Modern anuran frog, *Rana*. **C.** Modern urodele salamander, *Ambystoma*. **D.** Modern caecilian gymnophonian, *Chthonerpeton*. Note that caecilians have retained a fully formed skull while anurans and urodeles display significant loss or reduction of major bony skull elements. Abbreviations: en, external naris; eo, exoccipital; f, frontal (fused with parietals in frogs); it, intertemporal; j, jugal; l, lacrimal; m, maxilla; n, nasal; p, parietal; paf, parietal foramen; pf, postfrontal; pm, premaxilla; po, postorbital; pp, postparietal; pr, prootic; prf, prefrontal; q, quadrate; qj, quadratojugal; sm, septomaxilla; sq, squamosal; st, supratemporal; t, tabular. (*from Romer, after Watson, Marcus*)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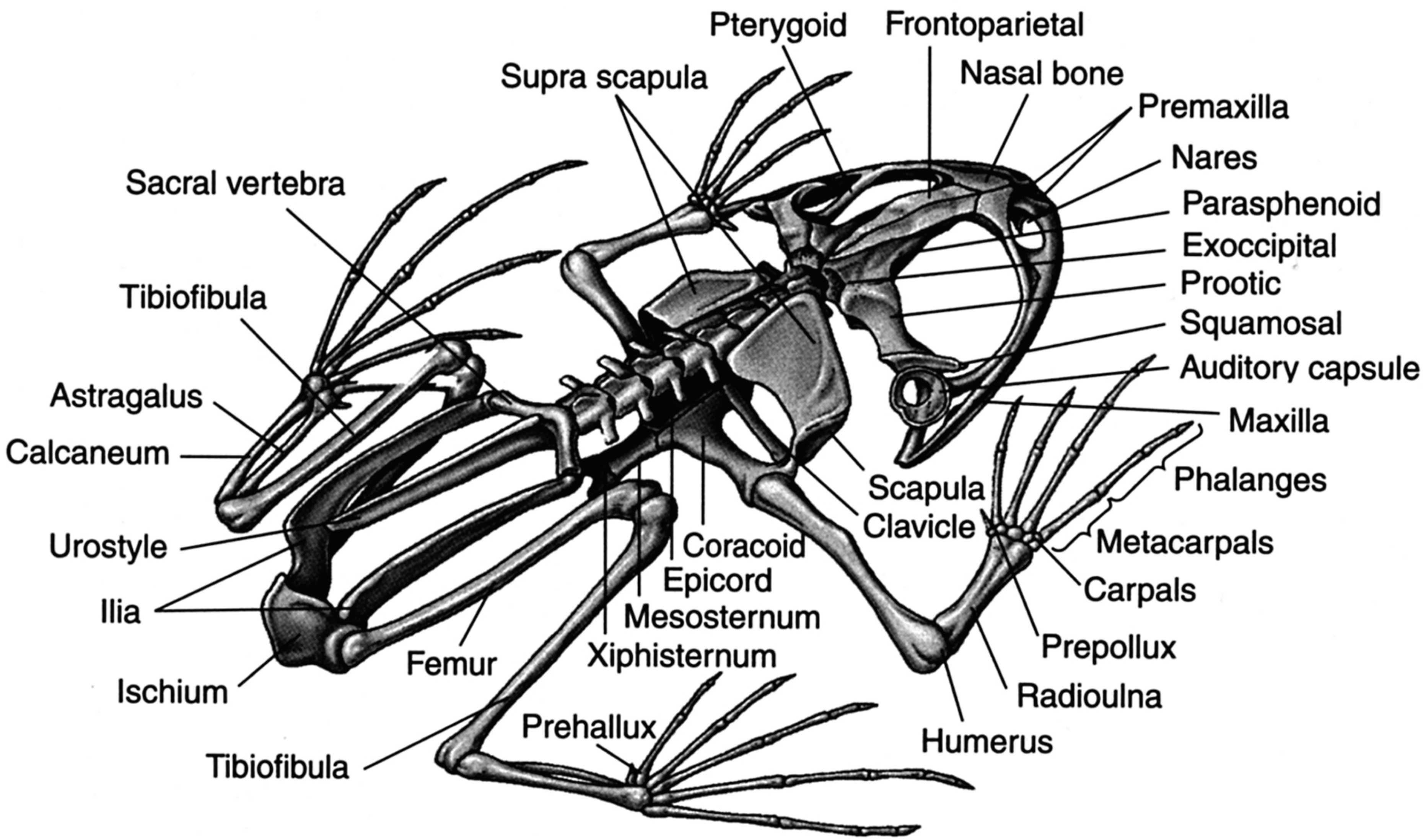

FIGURE 119. Skeleton of a bullfrog, *Rana catesbeiana* (Anura).
(*from Hickman, Roberts & Larson*)

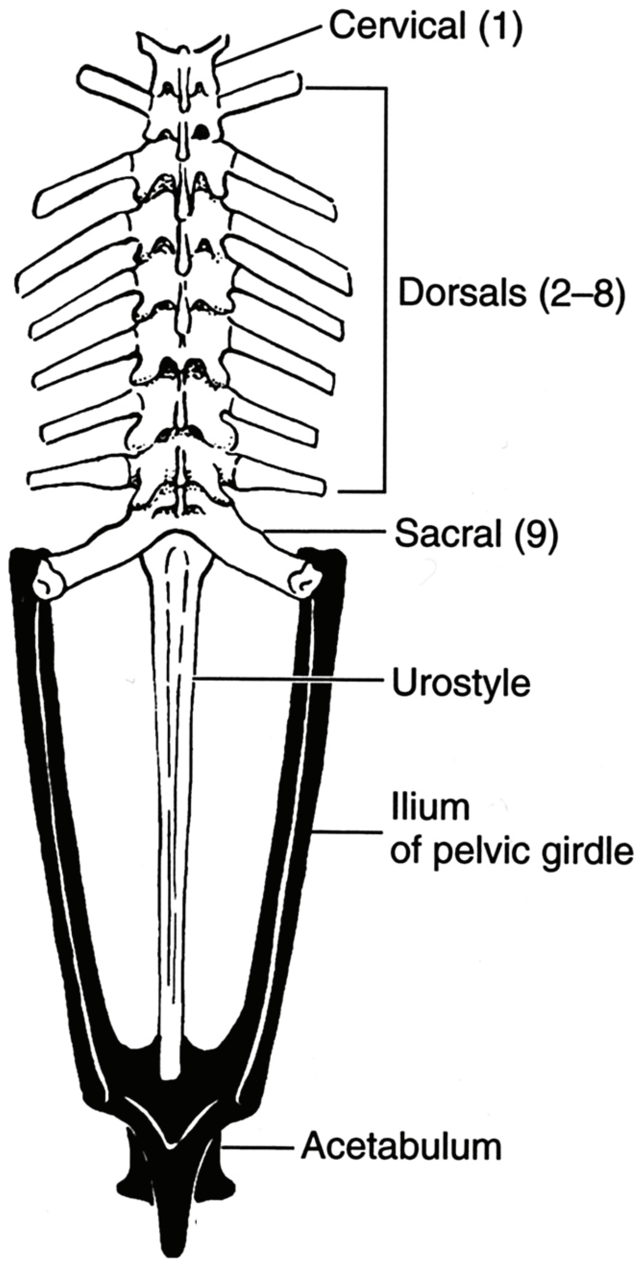

FIGURE 120. Vertebral column and pelvic girdle of a frog: form and function of the anuran urostyle. The long illium of the pelvic girdle is braced against the sacral vertebra. The urostyle consists of a series of fused postsacral vertebrae. (*from Kent and Miller*)

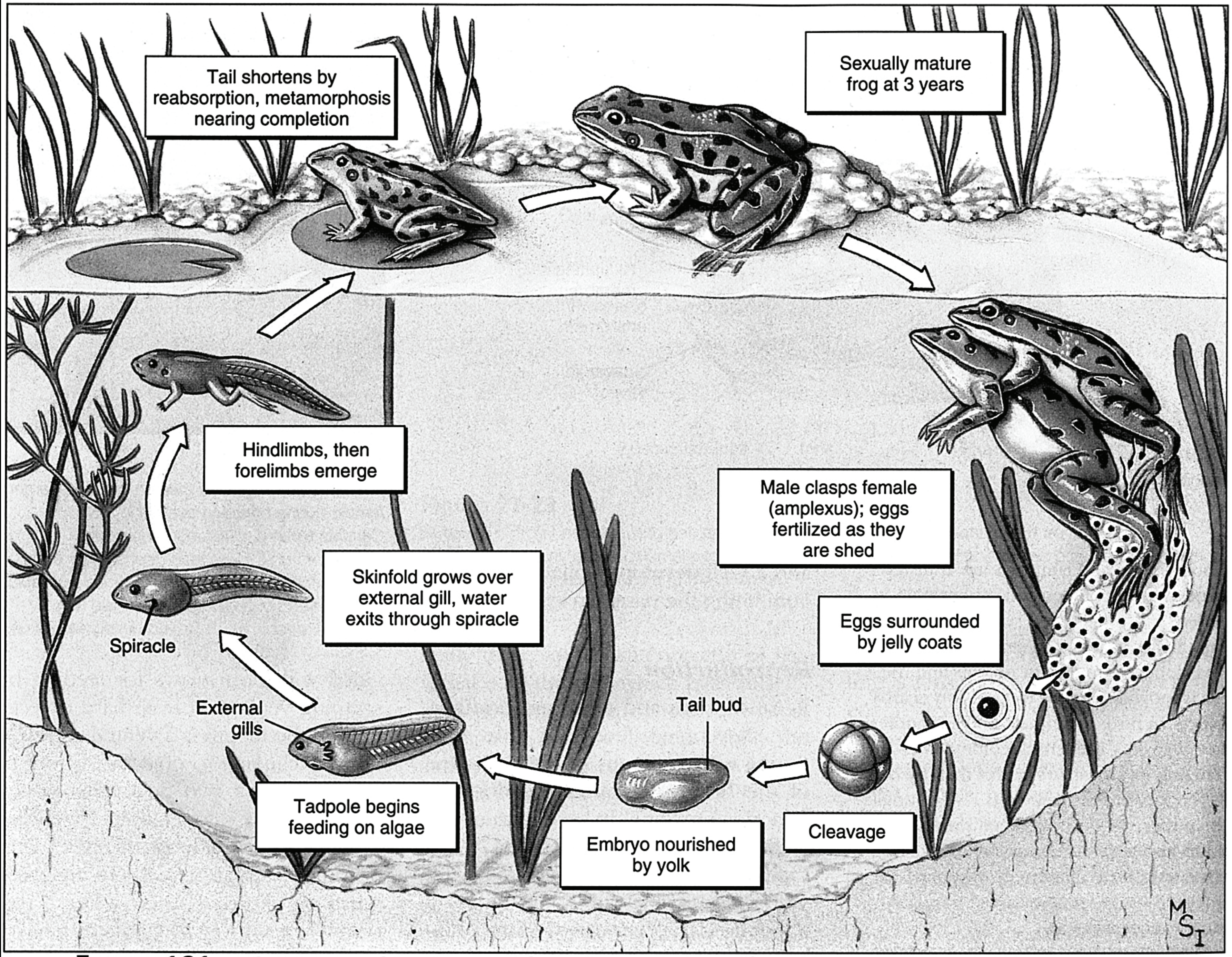

FIGURE 121. Life history of the leopard frog, ***Rana pipiens.*** (*from Hickman, Roberts & Larson*)

Caecilidae – common caecilians

Ambystomidae – Mole Salamanders

Ambystomidae – Mole Salamanders


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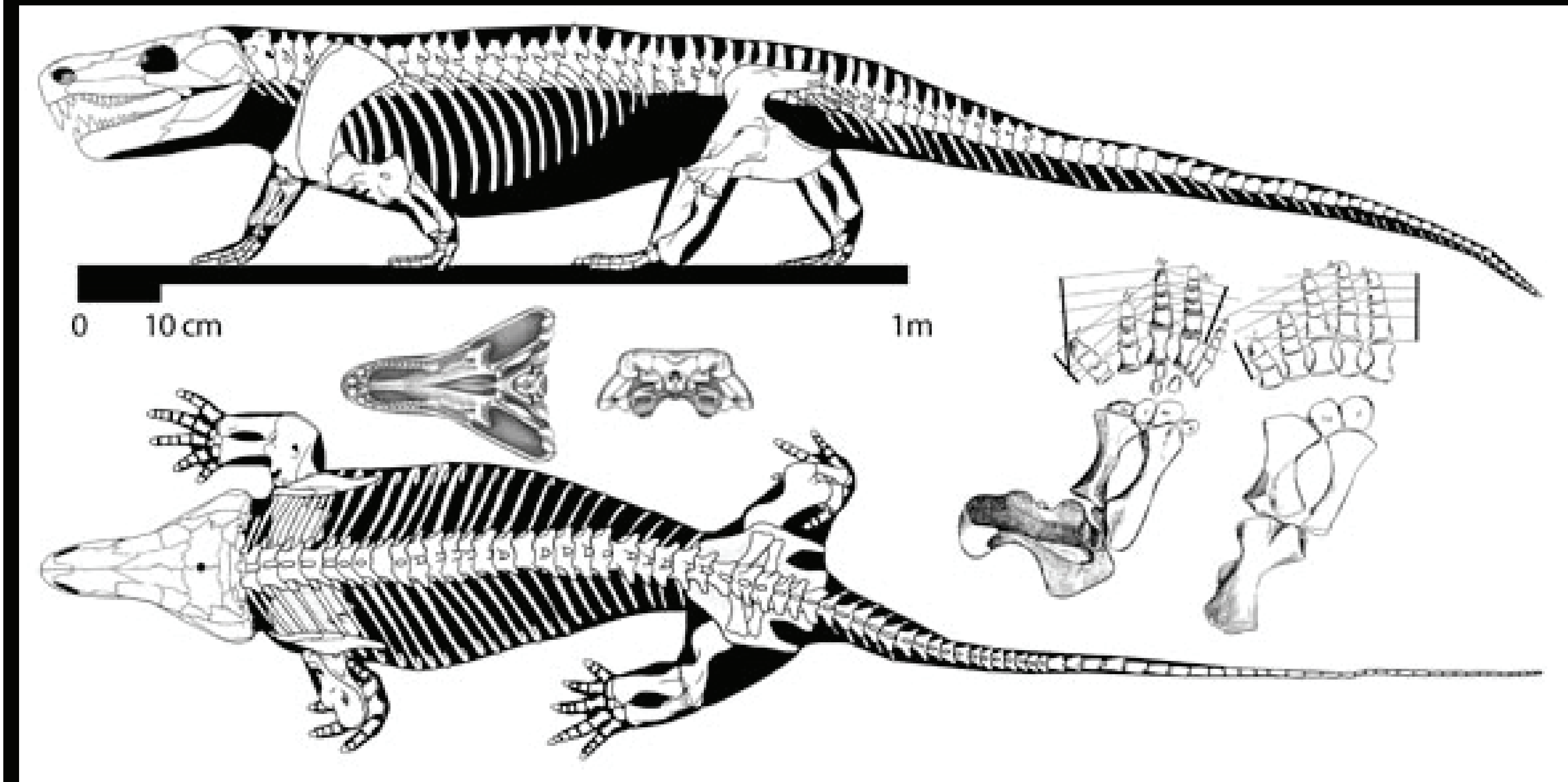
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