THE SKELETAL SYSTEM

INTRODUCTION

The internal *endoskeleton* of vertebrates provides support and protection for the softer body parts. It is the fundamental system upon which the body is built. A paleontologist can reconstruct an entire organism from a study of its bones alone.

Two types of skeletal bones are recognized in the higher vertebrates. The first is *endochondral bone* where solid bone has replaced earlier embryological cartilage. These are exemplified by our arm and leg bones. Others, known as *dermal* or *membrane bones,* have no cartilaginous precursers but develop directly within the dermis. These are best exemplified by the bones atop our cranium.

The most striking feature of the shark's skeleton is its being made entirely of *cartilage*. It thus exhibits a ''fetal'' characteristic in remaining cartilaginous during the animal's entire life. Although one may find some areas of ossification due to deposits of calcium salts, they do not form the complex pattern of haversian systems characteristic of the higher vertebrates. The *dermal skeleton* is missing entirely in the shark, except for its placoid scales, teeth and spines.

The best way of studying the shark's skeleton is by the use of mounted specimens of the skeleton. These are usually preserved in fluid or in a solid transparent block of plastic. Mounted skeletons of the entire animal or of its parts such as the skull or the pelvic appendages may be purchased. Although the specimens preserved in fluid may be handled and manipulated, it is best to leave the preparation in the jar, for the material is extremely fragile and delicate and can break easily. Thin parts such as fins may tear from the main skeleton at the slightest touch. Identify the parts of the skeleton preparations by studying the photos and diagrams in this chapter.

The skeleton may be divided into two main areas, the *axial skeleton* and the *appendicular skeleton*.

THE AXIAL SKELETON

In vertebrates, this portion of the skeleton consists of the skull, the vertebral column, and the rib cage.

The Skull—Chondrocranium

Two regions of the skull or chondrocranium are identified, the *neurocranium* and the *splanchnocranium*. Learn to locate and identify the parts listed below.

NEUROCRANIUM — This is the anterior and more dorsal portion of the skull. It protects the brain and the associated sense organs.

Rostrum — The most anterior portion is known as the *rostrum*. It is medially located, tapered anteriorly almost to a point, resembling a bird's beak. It is the support for the shark's snout. Dorsally it is hollowed-out and trough-shaped, forming the *precerbral cavity,* which in life is filled with a gelatinous substance. Ventrally it is keel-shaped, with the keel, the *rostral carina,* extending from about one-half its length posteriorly.

Nasal Capsules — Two large spheres project laterally at the posterior end of the rostrum. These are the *nasal capsules*. Their walls are very thin and therefore often destroyed in the preparation of the skeleton. In the diagrams they are complete and you may see their external openings, the *nares,* ventrally.

Orbits — Further caudally note the large sockets for the eyes, the *orbits,* one on each side, and the *supraorbital crest* dorsally protecting the socket.

Otic Capsules — Behind the eye sockets near the posterior end of the skull, two more large lateral depressions are found on the chondrocranium, the *otic capsules,* one on each side. These contain the inner ears.

Foramina — The chondrocranium is pierced by many perforations, or *foramina*.

Epiphysial Foramen — Mid-dorsally, right behind the rostrum, find the *epiphysial foramen,* through which the *epiphysis,* or *pineal gland,* projects. In many primitive vertebrates the pineal body serves as a third eye.

Superficial Ophthalmic Foramina — Also dorsally, above each orbit is a lateral line of about ten foramina, the *superficial ophthalmic foramina,* for the passage of branches of cranial nerves V and VII (the superficial ophthalmic trunk).

Endolymphatic Fossa — Continuing mid-dorsally, above the otic capsules, one may find a large depression, the *endolymphatic fossa*. Within this fossa are the anterior paired openings of the *endolymphatic foramina* and the more posterior *perilymphatic foramina*. These pass ventrally, by means of ducts to the inner ears within the otic capsules.

Rostral Fenestrae — On the ventral surface the most prominent foramina are the large *rostral fenestrae,* anteriorly located medial to the nasal capsules, on each side of the rostral keel. They open to the cranial cavity.

Notochord — The posterior ventral surface of the skull is flat, covered by a *basal plate*. Along the mid-ventral line, below the surface of the basal plate, one may see a white strand of calcified cartilage. This indicates the position of the *notochord* which persists even in the adult shark. At the anterior end of the notochord, on the ventral surface of the chondrocranium is the *carotid foramen* through which the internal carotid arteries enter the cranial cavity.

Occipital Region — The posterior end of the skull, the *occipital region,* is nearly rectangular in shape. Dorsal to the notochord note the *foramen magnum* which serves as a passageway for the spinal cord out of the cranium. A pair of knuckle-like projections seen ventrally on either side of the foramen magnum are the *occipital condyles*. They serve as articulation points between the chondrocranium and the vertebral column, although fish show very little movement at the occipitovertebral joint. Lateral to the occipital condyles on the posterior edge of the chondrocranium there are two large foramina. The more medial is the *vagus foramen* for the vagus nerve, while the more lateral, the *glossopharyngeal foramen,* serves the nerve of the same name.

Orbit (lateral view) — Looking at the chondrocranium laterally, within the orbital socket, one may see two large foramina, the anterior one the *optic foramen* for the optic nerve and the posterior one, the *trigeminofacial foramen* for the trigeminal and facial nerves. Several smaller foramina for smaller cranial nerves and vessels may also be found. In some preparations one may also see within the orbit, arising from its medial wall a small cartilaginous disc supported by a slender stalk, resembling a golf tee. It is known as the *optic pedicel*. It serves to support the eyeball. A paired process projects at the posterior end of the orbital socket, the *basitrabecular process* which articulates with the upper jaw.

SPLANCHNOCRANIUM — This second portion of the skull is ventral and posterior to the neurocranium. It is called the *splanchnocranium,* or *visceral cranium,* because it consists of the skeletal elements supporting the visceral wall, particularly in the areas of the mouth and the pharynx. The skeletal *visceral arches* form the jaws and the supports for the gill arches.

Visceral Arches — In the jawless fish, *Agnatha,* one finds up to ten visceral arches supporting the mouth parts and gills. They are fused to each other and to the top of the cranium forming a "branchial basket." In the *Squalus acanthias* shark there are only seven.

Mandibular Arch — The first visceral arch, the *mandibular* arch, is modified to form the upper and lower *jaws*. The upper jaw consists of the paired *palatoquadrate* cartilages. It is tied by ligaments to the chondrocranium. The lower jaw consists of the paired *Meckel's* cartilages. They hinge at their caudal ends to form the *angles* of the jaw. A slender pair of *labial cartilages* may be seen on the lateral surfaces of the jaws. They support the lips and help to further strengthen the sides of the jaw. Several rows of sharp, pointed, triangular *teeth,* modified *dermal denticles,* are located at the edges of the jaw. The back rows serve as replacement teeth when the anterior ones are lost or worn out.

Hyoid Arch — The second visceral arch is the *hyoid arch*. It lies immediately posterior to the jaws and extends to the otic capsules. The *spiracles* are located just anterior to the dorsal portion of the hyoid arch. The hyoid arch consists of a single mid-ventral segment, the *basihyal,* which forms the floor of the mouth, and two paired elements, the *ceratohyal* and *hyomandibular* cartilages. The ceratohyal extends dorsolaterally from the basihyal to the angle of the jaw. These elements also serve to support the tongue. Completing the hyoid arch dorsally is the paired hyomandibular cartilage which articualtes with the lateral surface of the otic capsule. The hyoid arch provides primary support for the jaws and is attached to them by ligaments.

The Gill Arches — The last five visceral arches, numbers 3 to 7, posterior to the hyoid arch, are known as the *gill arches,* or branchial arches, because they support the gill elements. They are "U"-shaped, with multi-jointed elements, with the upper (dorsal) portion incomplete. Ventrally, they are all united.

Each gill arch consists of several jointed cartilage elements. The most dorsal is the *pharyngobranchial,* which supports the dorsal portion of the pharynx. They point posteriorly but fail to unite with the vertebrae. The *epibranchial* and *ceratobranchial* segments continue ventrolaterally. Only three short *hypobranchial* elements continue ventrally. These are followed by the most ventral element, the *basibranchial*. There are only two of these in most dogfish, the more caudal one is usually larger and tapers posteriorly. Only the ceratobranchials and the epibranchials bear the *gill lamellae,* the surfaces upon which the exchange of respiratory gases takes place.

Many slender lateral projections are attached to the gill arches (see photos, pages 22 and 23). These are the *gill rays* which support the gill lamellae. Also, one may see shorter, more medial projections, the *gill rakers*. These prevent food from leaving the mouth and pharynx through the gill slits.

Parts of the visceral skeleton persist in the higher vertebrates, even in man. Our six auditory ossicles, parts of the temporal, sphenoid, mandible, and hyoid bones and the cartilage elements of the larynx are vestiges of the visceral skeleton of fishes.

The Vertebral Column and Ribs

In addition to observing the preserved skeletal preparations, you are to do your own dissection of the vertebral bones and ribs. Make a cross sectional cut of the tail between the second dorsal fin and the caudal fin. Your section should appear as the photo on page 25. Also remove a two-inch section of vertebral column just posterior to the first dorsal fin. Remove the skin and muscles to expose the vertebral bones. Refer to the photos and diagrams to help in your identification of parts.

The vertebral column consists of two types of vertebrae: *trunk vertebrae,* those of the main body, and *tail vertebrae*. Let us examine the tail vertebrae first, then see how the more anterior trunk vertebrae differ.

Observe the cross section of the tail and note that the vertebral column lies at the intersection of several *connective tissue septa* which separate the surrounding muscle. These septa will be named in the next chapter on the Muscular System.

TAIL VERTEBRAE — Each vertebra consists of a cylindrical central portion called the *centrum,* which bears a dorsal and a ventral arch of cartilage. The dorsal arch is the *neural arch*. Within this arch, the *spinal cord* passes through the *vertebral canal*. The ventral arch, known as the *hemal arch,* contains the *hemal canal,* through which pass the *caudal artery* and *caudal vein*; the artery dorsal to the vein. The end of each arch tapers to form a spine, the *neural spine* dorsally and the *hemal spine* ventrally.

The Centrum and the Notochord — The notochord runs through the middle of the *centrum*. The part of the centrum immediately adjacent to the notchord has become calcified and appears white. As explained earlier, this calcification, while it strengthens the vertebral column, is not like bone formation in higher vertebrates. Examine two centra in sagittal section. Note that they are shaped like a spool, concave at each end with a gelatinous substance in the core cavity between the two centra. This is also *notochordal tissue* that has persisted from an earlier, embryological stage. This type of centrum is called *amphicoelous*. The sagittal section also reveals that the parts of the centrum near the ends have the broadest notochordal tissue while those at the center have only a narrow band of notochord. This results in the diamond shape of the notochordal tissue within each vertebra.

The Neural Arch — When the *neural arches* of a series of vertebrae are viewed laterally, they seem to be composed of alternating, ''V''-shaped, triangular blocks. The block located above the centrum, with its apex pointing dorsally, is known as the *neural plate*. The other block, located in the joint between the centra, wedged between the neural plate elements, with its apex pointing ventrally, forms the *dorsal intercalary plate*. Each plate is perforated by a foramen. The dorsal roots of spinal nerves exit through foramina in the dorsal intercalary plate, while the ventral roots exit through the foramina in the neural plates. Find these in your specimen. Much smaller, *ventral intercalary plates* are found ventrally between vertebrae.

The Hemal Arch — The *hemal arch,* below the centrum, is composed of repeated blocks of cartilage, the *hemal plates*. In the lateral wall of the hemal canal are *foramina* through which branches of the caudal artery and vein exit.

TRUNK VERTEBRAE — The structure of the trunk vertebrae is basically the same as the tail vertebrae, lacking, however, the hemal arches. Instead they have short, ventrolateral processes, *basapophyses,* that project from the sides of the septum of each vertebra. Small *rib* cartilages, extending horizontally, are attached to these projections.

THE APPENDICULAR SKELETON

The *appendicular skeleton* refers to the cartilages of the *pectoral* and *pelvic* girdles and to their respective *fins*.

Pectoral Girdle and Pectoral Fins

Study the preserved skeletal preparations and the accompanying photographs.

PECTORAL GIRDLE — A ''U''-shaped structure which encircles the ventral side of the trunk. It consists of a median ventral *coracoid bar* which articulates laterally with the *scapular* and *suprascapular cartilages*. These have a depression, the *glenoid fossa,* for articulation with the *pectoral fin*.

PECTORAL FINS — They consist of three *basal fin cartilages* which articulate with the girdle at the glenoid surface. From anterior to posterior they are the *propterygium, mesopterygium,* and *metapterygium*. These articulate distally with many slender *radial cartilages*. The most distal portions of the pectoral fins are broad, yet thin and flexible to allow for free movement. These are the *ceratotrichia*. The supporting cartilages of the basal and radial components are collectively known as the *pterygiophores* (supporters of the fin).

Pelvic Girdle and Pelvic Fins

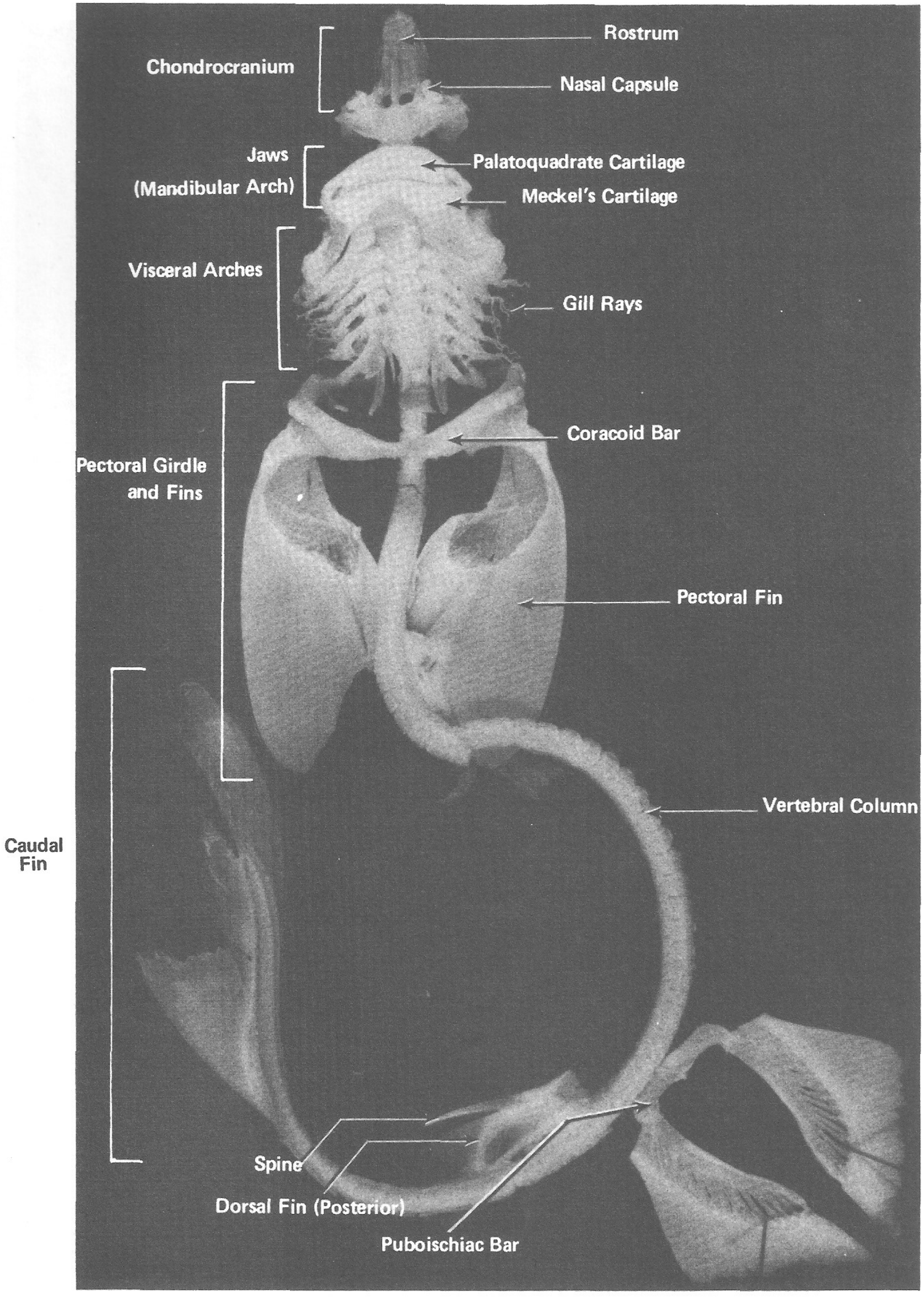
PELVIC GIRDLE — The *pelvic girdle* of the dogfish shark is composed of a single transverse rod of cartilage, the *puboischiac bar,* located in the ventral abdominal wall just anterior to the cloaca. At each end of the bar there extends a short dorsolateral process, the *iliac process*.

PELVIC FINS — The *basal cartilages* of the *pelvic fins* consist of only two elements,the *propterygium* and the much longer *metapterygium* which extends caudally. As in the pectoral fins, there are a series of *radial cartilages* which articulate with the basal cartilages. Again, the most distal portions of the fins are known as *ceratotrichia*. In male sharks a highly modified radial cartilage forms the *clasper,* by which sperm are transferred to the cloaca of the female.

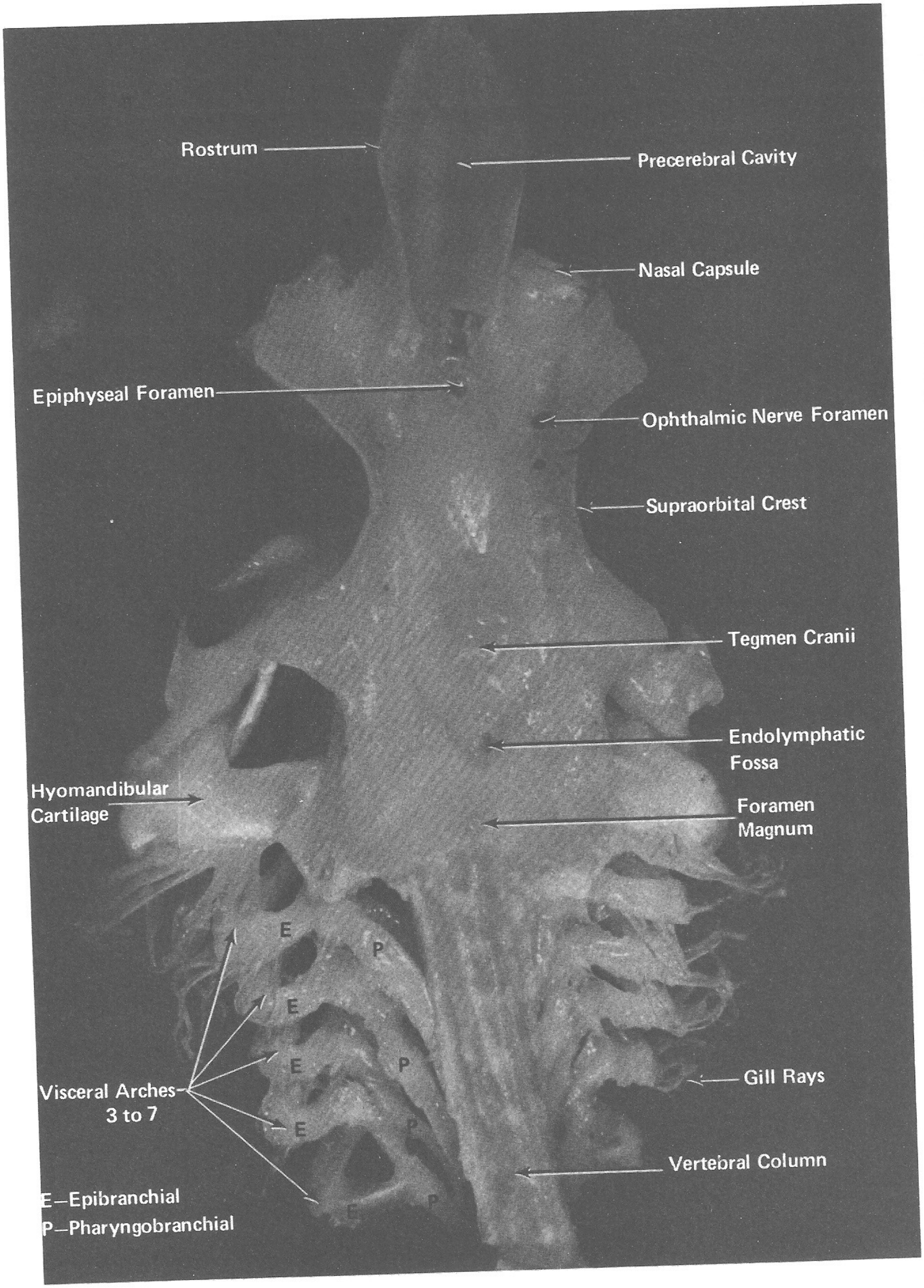
Dorsal and Caudal Fins

DORSAL FINS — The *dorsal fins,* one anterior and the other more posterior, although not a part of the appendicular skeleton, are here described because they are similar in structure to the pectoral and pelvic fins. The larger *basal cartilages* are next to the vertebral column, the smaller *radial cartilages* are more distal. Finally, the thin parallel most distal rays are the *ceratotrichia*. A sharp pointed *spine* projects dorsally from the anterior end of each dorsal fin.

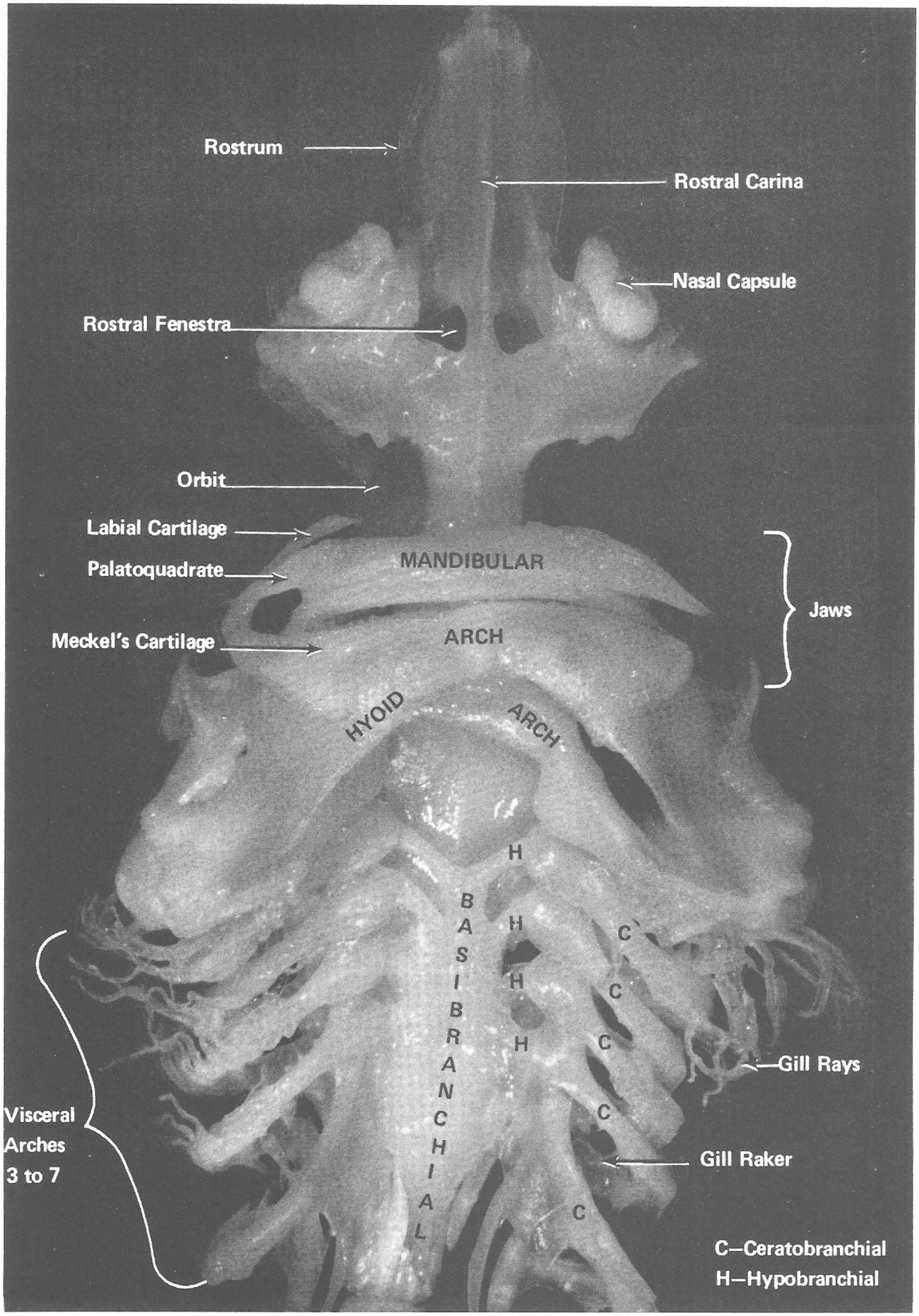
CAUDAL FIN — One may also find *ceratotrichia* on the caudal fin. These articulate directly with the neural and hemal arches. The end of the vertebral column turns upward into the dorsal part of the caudal fin. This type of tail is termed *heterocercal*.



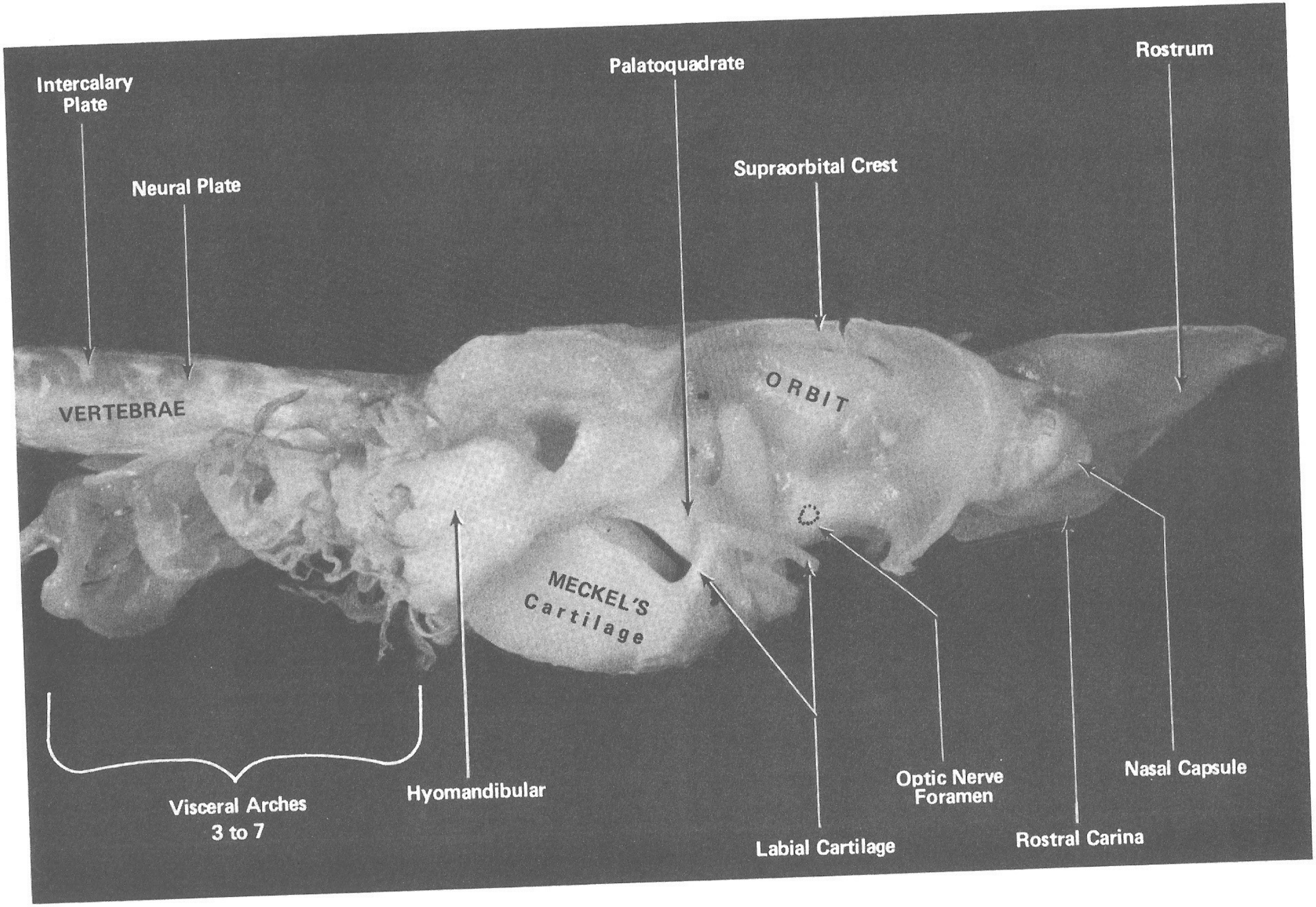
THE SKELETON — VENTRAL VIEW



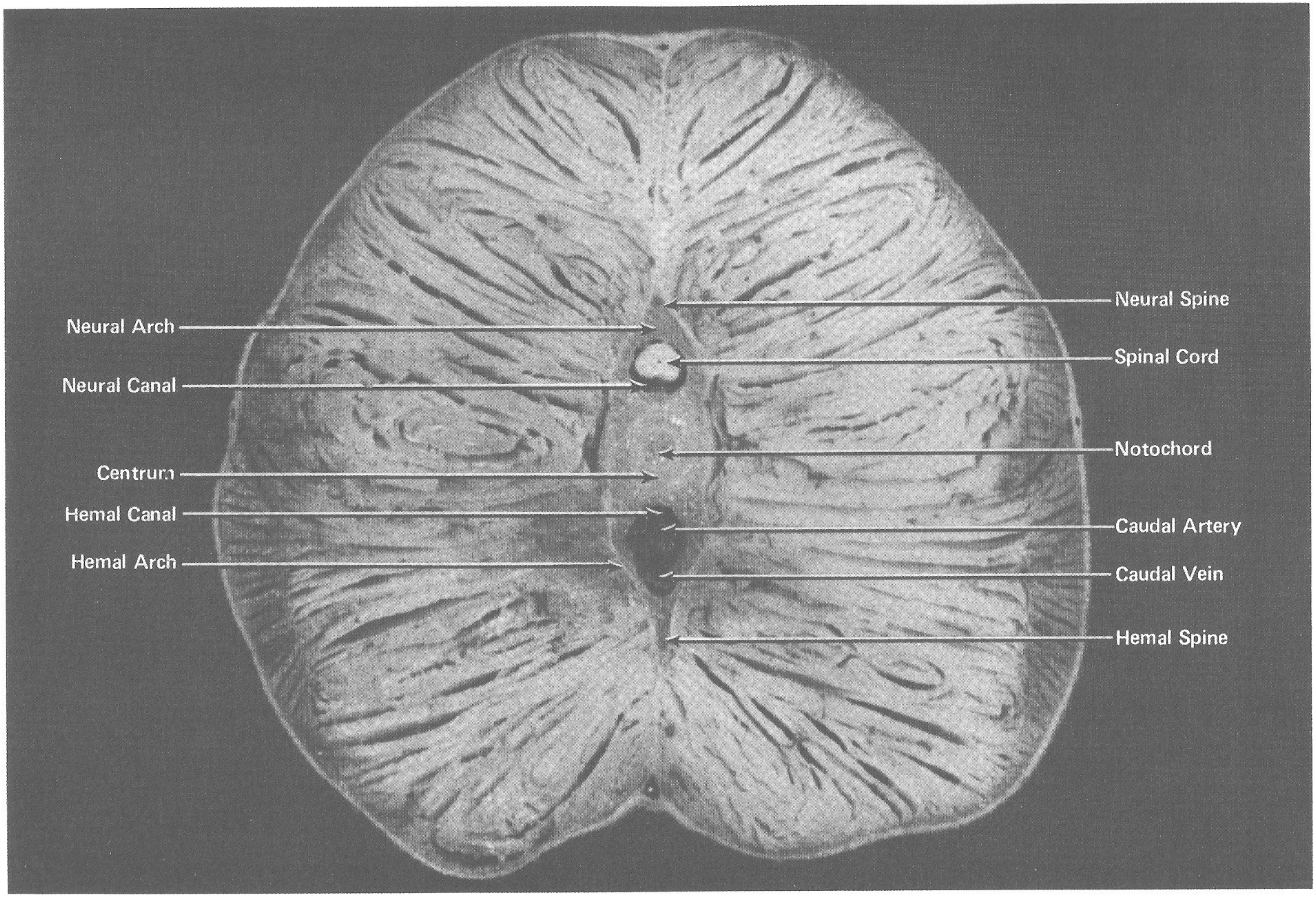
SKULL – DORSAL VIEW



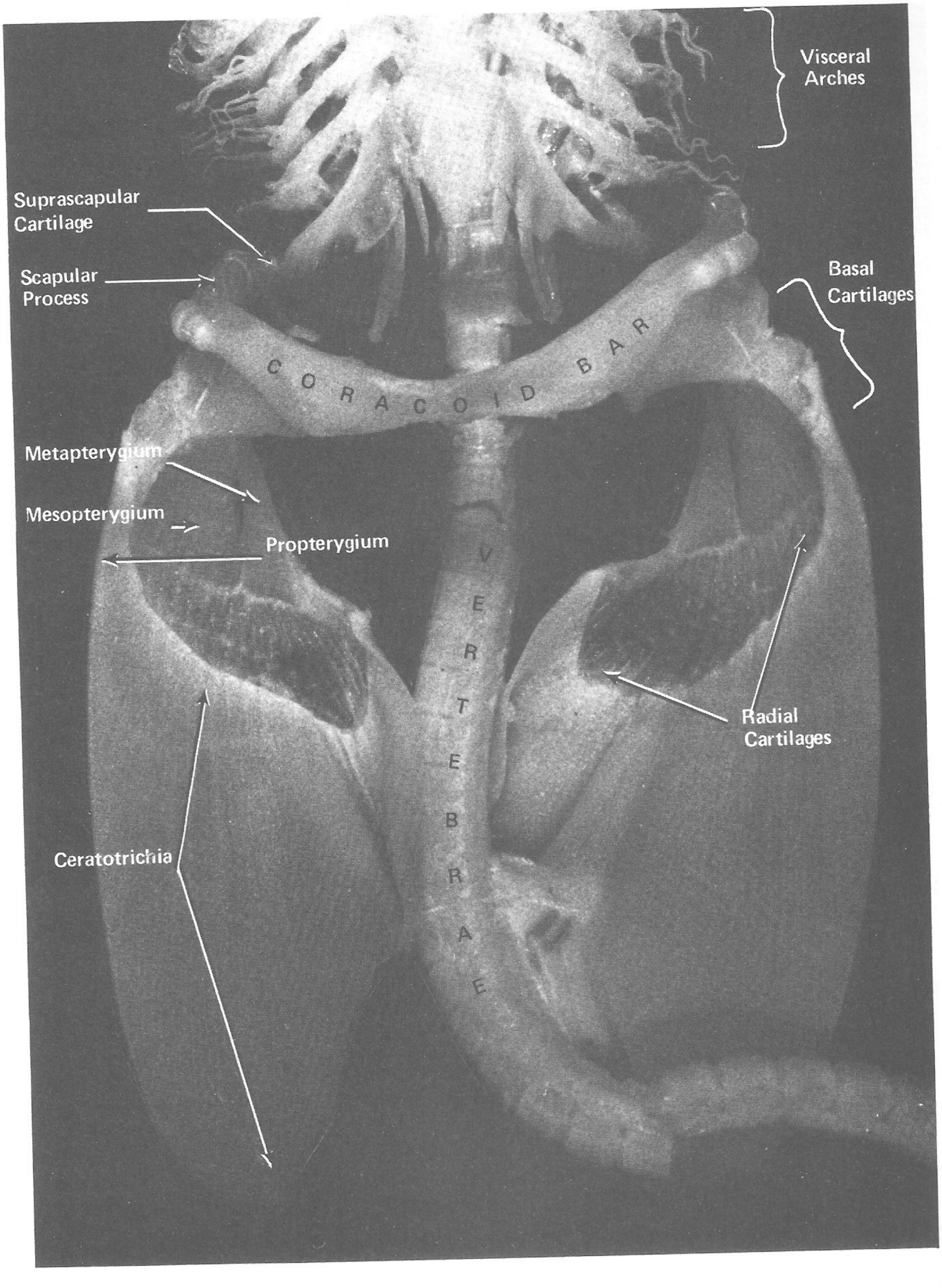
SKULL — VENTRAL VIEW



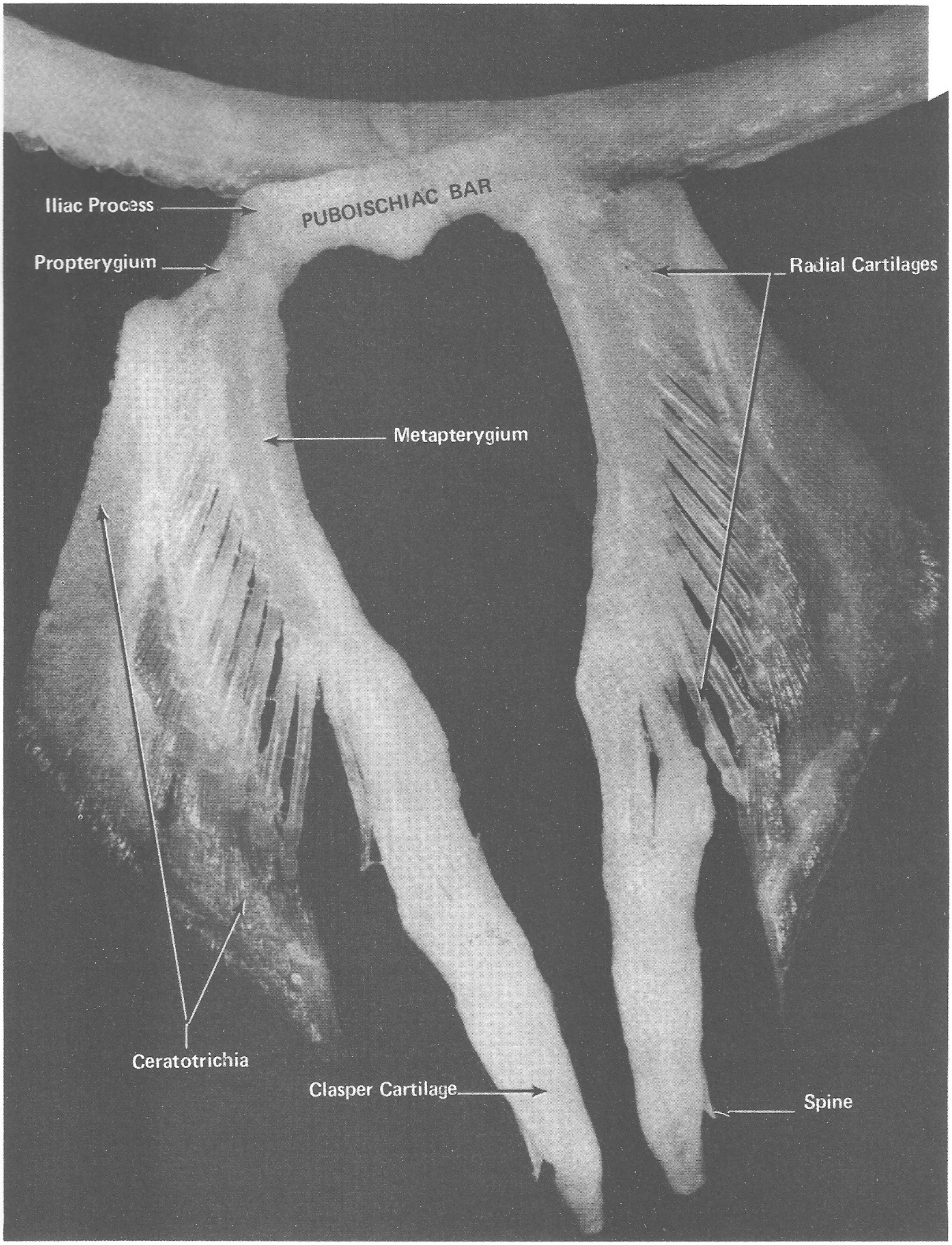
SKULL — LATERAL VIEW



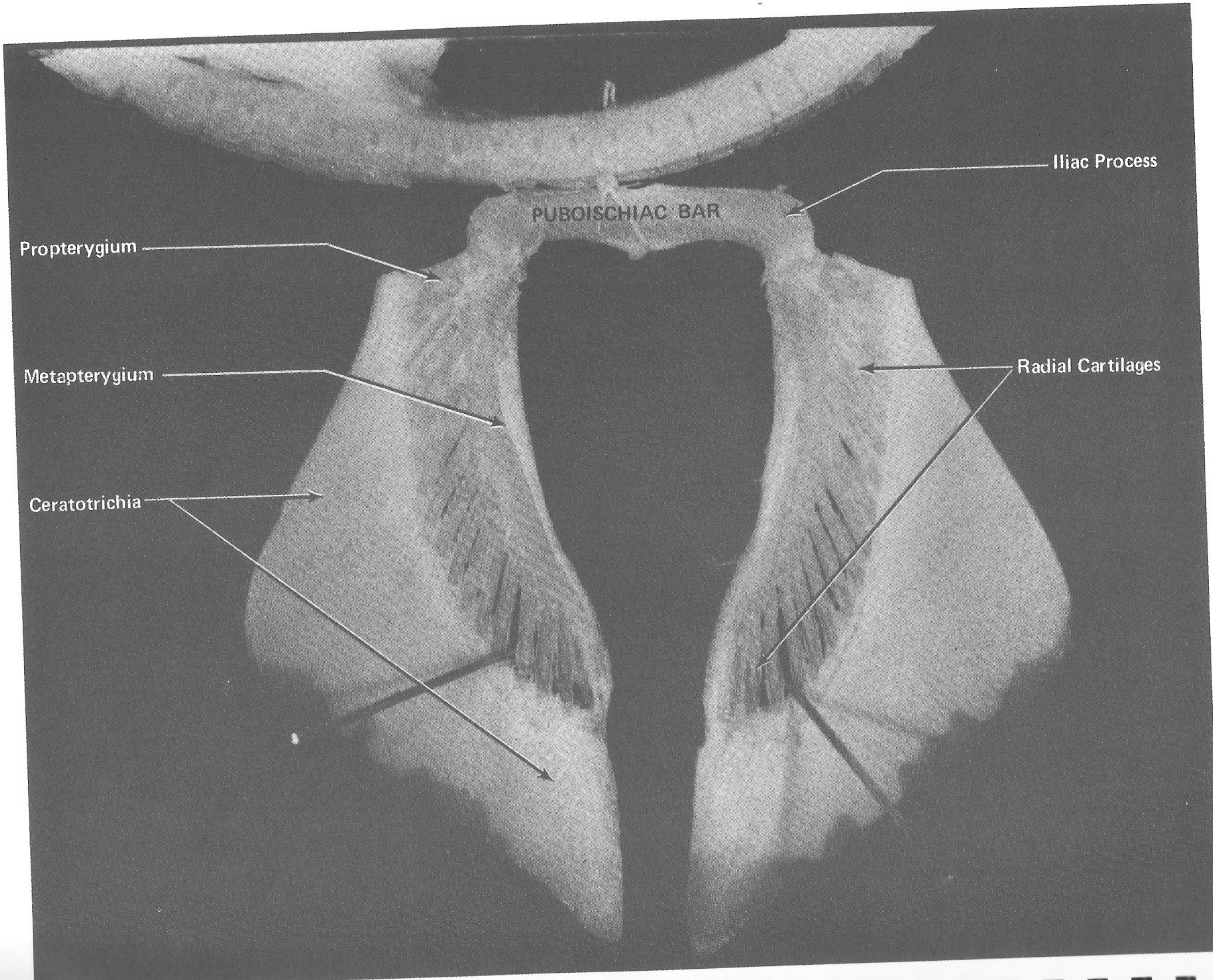
CAUDAL VERTEBRA – CROSS SECTION



PECTORAL GIRDLE AND FINS – VENTRAL VIEW



PELVIC GIRDLE AND FINS, MALE – VENTRAL VIEW



PELVIC GIRDLE AND FINS, FEMALE – VENTRAL VIEW

THE MUSCULAR SYSTEM

INTRODUCTION

Many of the introductory remarks concerning the muscular system, while concerned primarily with the dogfish shark, are equally true for the higher vertebrates.

The muscles of *Squalus* are a good example of the musculature in primitive vertebrates. In the higher forms these have been modified by migrations, splitting, fusion, or a combination of factors. In the shark the natural groups of muscles can be recognized, identified and studied in the adult, while in higher forms the original natural muscle groups can only be found in the embryo.

SKELETAL MUSCLES enable the body to move. They are involved in moving the entire shark through the water as well as in moving individual visceral structures such as the jaws and gill arches.

Most muscles are firmly anchored to the skeleton at one end, the *origin* of the muscle, while the other end is attached to the skeletal element to be moved, and is known as the *insertion*. The fleshy central portion is termed the *belly*. The ends of a muscle are attached to the skeleton most often by means of a narrow band of connective tissue called a *tendon*. They may also be joined directly to the *periosteum* of a bone. Finally muscles may be united with each other or with a skeletal element by means of a broad, flat sheet of tendinous tissue known as an *aponeurosis*.

As you dissect, locate the origins and insertions of the muscles studied. Then free the muscle from other muscles and from the nerves and blood vessels associated with it. The fine, transparent connective tissue which binds adjacent muscles is *deep fascia,* while tougher and more fibrous *superficial fascia* connects the skin to the muscles below. When the muscle has been freed, pull it gently. This will duplicate the muscle's normal contraction. Observe which bones or organs are moved and which remain relatively stable.

The *action* of a muscle results from its contraction. Muscles are usually arranged in *antagonistic* pairs. This means that while a muscle will cause a structure to move in one direction, its antagonist will cause it to move in the opposite direction.

ACTIONS OF MUSCLES

Flexion — to bend at a joint decreasing the angle at that joint; examples: elbow or knee joint.

Extension — to straighten joint increasing the anle at that joint.

Adduction – to move appendage toward sagittal midline; example: lowering arms from shoulder level to rest at sides.

Abduction – to move appendage away from sagittal midline; example: raising arms from rest at sides to shoulder level.

Supination — to turn palm of hand upward.

Pronation — to turn palm of hand downward.

Rotation — to move a structure about a point; example: turning head from side to side.

Circumduction — when the distal end of a limb describes a circle while the proximal end remains fixed, as the vertex of a cone; example: the movement of the extended arm in drawing a circle on the blackboard.

The study of the shark musculature will be divided into three aspects. We shall first study the major body muscles which propel the fish through the water, then those of the gill (branchial) area and the head, and finally, those of the fins (appendicular muscles).

BODY MUSCULATURE

The Dissection

Remove a section of skin in order to observe typical body musculature.

Proceed as follows.

Make a very shallow incision into the skin at the mid-dorsal line, directly posterior to the second dorsal fin. Continue to cut caudally for about two inches. At each of the two ends, cut the skin ventrally along the sides of the body till you reach the mid-ventral line. Do not cut too deeply for you may destroy the muscles you wish to study. Use a blunt instrument such as a probe, the handle of your scalpel, even your fingers, to remove the section of skin whose perimeter you have just cut. If the shark's skin adheres very tightly to the underlying musculature, the use of a scalpel may be necessary. Then, use your scalpel to make a clean cross-sectional cut, through the entire body of the shark, cutting off the tail, directly posterior to the second dorsal fin. This affords a view of the transverse as well as the lateral arrangement of muscle bundles.

Identify the parts in your dissection as described below. Consult the accompanying photos. See photo, page 42.

MYOTOMES (MYOMERES) — The muscles you have exposed are composed of segments termed *myotomes*. They are arranged in a zigzag, ''W''-shaped pattern along the entire length of the animal's trunk and tail. Only in the gill region are they partially interrupted. The myotomes are separated from one another by connective tissue partitions called *myosepta*. The dorsal portion is clearly separated from the ventral portion by the *horizontal (transverse) septum*, a band of connective tissue between the muscle bundles. This septum extends lateraly toward the position of the *lateral line* on the outer surface of the trunk. The bundles of myotomes, dorsal to the horizontal septum, are known as *epaxial*, while those ventral are known as *hypaxial*. Along the mid-ventral region, from coracoid bar to anus, a band of white connective tissue separates the myotomes of the right and left sides. This is the *linea alba*. The direction of the fibers of each myotome is longitudinal on either side of the horizontal septum and somewhat oblique near the more dorsal and ventral extremes.

Examine the cross-sectional view of the muscle bundles and identify two more connective tissue septa. The *dorsal median septum* lies between the right and left epaxial bundles. The *ventral medial septum* between the right and left hypaxial bundles in the region caudal to the anus. Recall that anterior to the anus, the linea alba separates right and left hypaxial bundles.

MUSCLES OF THE BRANCHIAL AND HEAD REGIONS

The epaxial and hypaxial muscle bundles of the trunk and tail are interrupted by specialized muscles in the area of the gills (branchial), and below the pharynx (hypobranchial). They are involved with opening and closing the gill pouches during the exchange of respiratory gases and in opening and closing the jaws.

The Dissection

Remove the skin of the dogfish as follows: Start mid-ventrally at the pectoral fins and proceed anteriorly to the lower jaw. Continue to cut and remove the skin laterally toward the right side. Remove all of the skin covering the gills, below and posterior to the eye around the spiracle then dorsally to the top of the head. Take care to avoid removing the superficial muscles.

After the skin has been removed, observe the regions of the head and gills in lateral view.

The muscles in this region are involved with feeding and respiration, opening and closing the jaws, swallowing, and passing water across the gills by compressing and expanding the gill pouches. They are arranged in series, corresponding to the visceral arches which they serve.

These *branchial muscles* are divided into three groups:

1. **Superficial constrictors**
2. **Levators**
3. **Interarcuals**

A fourth group, the **hypobranchials,** form the floor of the pharynx and will be viewed from the ventral surface. They help in opening the mouth, swallowing, and expanding the gill pouches.

Find and identify the muscles described on your specimen.

SUPERFICIAL CONSTRICTORS — As their name indicates, they are primarily involved in constricting the gill muscles and compressing the gill pouches. Their action is, however, modified in visceral arches 1 and 2 where they move the jaws.

First Dorsal Constrictor — This is composed of three muscles:

1. **Adductor Mandibulae (Quadratomandibularis)**
2. **Spiracularis (Craniomaxillaris)**
3. **Preorbitalis (Suborbital)**

Adductor Mandibulae (Quadratomandibularis) — This easily seen large mass of muscle is located at the angle of the jaws. It arises from the posterior portion of the palatoquadrate cartilage and inserts on Meckel's cartilage.

Spiracularis (Craniomaxillaris) — This small muscle lies on the anterior wall of the spiracular valve. It lies posterior to one of the larger levator muscles (to be described later). It has been questioned whether it is a separate muscle or a part of the larger levator.

Preorbitalis (Suborbital) — This is a deeper muscle, cylindrically shaped, which lies between the upper jaw and the eye. It originates in the mid-ventral surface of the cranium and inserts on Meckel's cartilage.

First Ventral Constrictor

Intermandibularis — This is a broad, thin, ventral constrictor muscle of the first visceral arch. It lies posterior to the mouth. It originates at the mid-ventral raphe of Meckel's cartilage and inserts at its ventral borders. It acts to raise the floor of the mouth and thus to force water out of the gill slits.

Second Constrictor — This is composed of two muscles:

1. **Hyoid Constrictor**
2. **Interhyoid**

Hyoid Constrictor — This muscle lies in the region of the second, or hyoid, arch and is wider than the others. It extends from the first gill slit to the angle of the jaw. It includes both dorsal and ventral fibers.

Interhyoid — This ventral muscle is the second of the hyoid arch constrictors. It is the anterio-ventral extension of the hyoid constrictor. It is broad and thin and lies near the ventral midline. In order to expose this muscle, it will be necessary to dissect a part of an overlaying muscle, the intermandibularis, a constrictor of the first visceral arch.

Third to Sixth Constrictors — Beginning with the area just dorsal to the gill slits, find the *dorsal constrictors,* and ventral to the gill slits the *ventral constrictors*. They are numbered 3 to 6 and correspond to the gill arches of the same number. These constrictors are similar to each other. A white vertical connective tissue band, the *raphe,* extends above and below each gill slit and separates adjacent constrictor sets. They overlap each other anteriorly; thus, each is partly hidden by the constrictor anterior to it.

LEVATORS — The *levator* branchial group consists of three distinct muscles. As the name indicates, they raise the jaws and the five gill arches.

First Levator — *Levator Palatoquadrati (Levator Maxillae Superioris)* — This muscle is located anterior to the *spiracle*. It arises from the side of the otic capsule and inserts on the palatoquadrate cartilage.

Second Levator — *Levator Hyomandibulae (Hyoid Levator)* — The second levator muscle is located caudal to the first, in back of the spiracle. It also originates on the otic capsule and inserts on the lateral surface of the hyomandibular cartilage. It also acts to raise the jaws.

Third to Sixth Levators — *Cucullaris* — This muscle acts as unified levator of all five gill arches. It lies dorsal to the superficial gill constrictors and is triangular in shape. It originates from the epibranchial musculature in the occipital region of the cranium to insert posteriorly on the pectoral girdle and the last gill arch. Another function of this muscle is to move the pectoral girdle and fin cranially and dorsally. For this reason it is also considered to be partly homologous to the *trapezius* muscle of higher vertebrates.

INTERARCUALS — These are a series of small muscles which act upon the gill arch cartilages. To see them it is necessary to cut dorsally into the gill pouches, separate the epaxial and cucullaris muscles and to expose the pharyngobranchial cartilages.

Dorsal (Medial) Interarcuals — These muscles extend between adjacent pharyngobranchial cartilages. They pull the gill arches cranially.

Lateral Interarcuals — These muscles extend from the pharyngobranchials to the adjacent epibranchial cartilages.

Subspinal — This muscle originates on the posterior portion of the cranium near the foramen magnum and inserts on the first pharyngobranchial cartilage. It, together with the dorsal interarcuals, draws the gill arches cranially.

Branchial Adductors — These small muscles extend between the epibranchial and ceratobranchial cartilages. They act to flex the branchial arches.

HYPOBRANCHIAL — Turn the shark ventral side up. These muscles are locate between the coracoid bar of the pectoral girdle and Meckel's cartilage (lower jaw). To see them all it is necessary to remove the superficial intermandibular, interhyoid muscles as well as the superficial ventral constrictors. They act in opening the mouth, swallowing, and expanding the gill cartilages.

Common Coracoarcuals — This muscle pair lies immediately anterior to the coracoid bar, from which it originates. Its fibers taper anteriorly and are continuous with those of the *coracohyoids, coracomandibular,* and *coracobranchials*.

Coracohyoids — This muscle pair originating from the *common coracoarcuals* continues cranially on either side of the mid-ventral line. It inserts on the basihyal, the ventral median cartilage of the hyoid arch.

Coracomandibular — A narrow muscle lying in the mid-ventral line between the two *coracohyoids*. It also originates from the *common coracoarcuals* and inserts upon Meckel's cartilage.

Coracobranchials — These muscles are deeper than the other hypobranchials. Five segments pass to the cartilages of the gill arches. They act to expand the pharyngeal cavity. The most posterior slip forms a part of the anterolateral wall of the pericardial cavity.

EPIBRANCHIAL — In the dorsal part of the shark the epaxial muscles, uninterrupted by the gills, continue their body pattern of segmentation till the chondrocranium.

APPENDICULAR MUSCLES

In fish the pattern of appendicular muscles is very simple. The fins do not undergo complex movements. The primary forward thrust is achieved by the movements of the body and the tail. The fins are for steering and maintaining stability.

Fin Musculature

PECTORAL FIN — Remove the skin of the pectoral fins; from both its ventral and dorsal surfaces. Also remove some of the skin immediately anterior to the fin.

Flexor and Extensor (Adductor and Abductor, Depressor and Levator)— You will find a single ventral and a single dorsal mass of muscle radiating toward the distal end of the fin. These are the *pectoral flexor* on the ventral surface and the *pectoral extensor* on the dorsal surface. The ventral flexor depresses the fin and pulls it forward, while the dorsal extensor raises the fin and pulls it posteriorly.

The ventral pectoral flexor originates on the coracoid bar and inserts on the pterygiophores of the fin, while the dorsal pectoral extensor originates on the scapular process of pectoral girdle and also inserts on the pterygiophores.

PELVIC FIN — The muscles of the pelvic fin are somewhat more complex than those of the pectoral fin. In addition, in males, part of the pelvic fin is modified as a *clasper* for the transfer of sperm to the female.

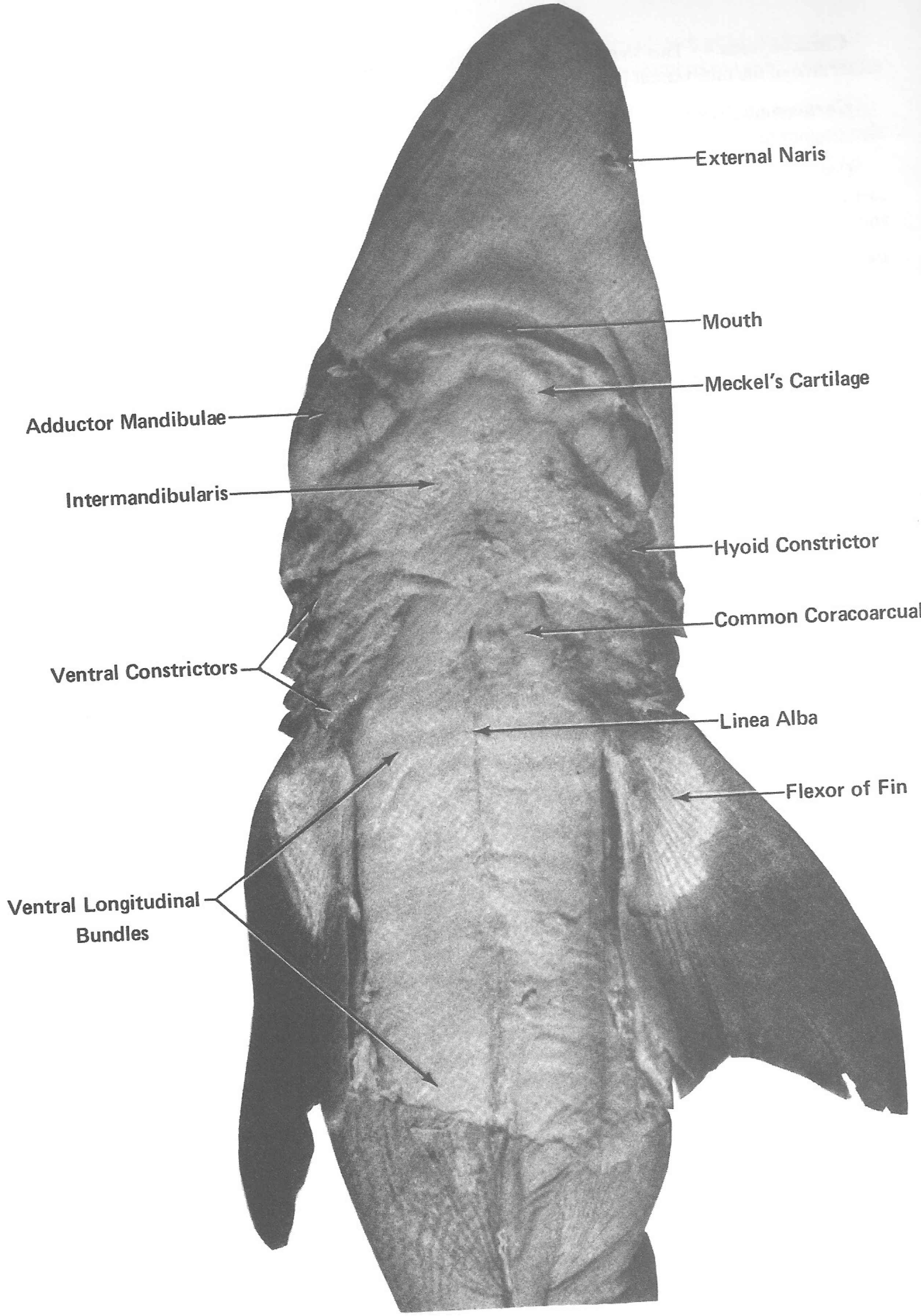
Remove the skin of one of the pelvic fins of a female shark from both its ventral and dorsal surfaces. Also remove some of the skin immediately anterior to the fin.

Flexor and Extensor (Adductor and Abductor, Depressor and Levator) — The muscle mass on the ventral surface of the fin, the *flexor,* may be divided into the *proximal pelvic flexor* muscle, and the *distal pelvic flexor* muscle. The proximal portion arises from the puboischial bar and inserts on the metapterygium; the distal portion originates from the metapterygium and inserts on the radial cartilages.

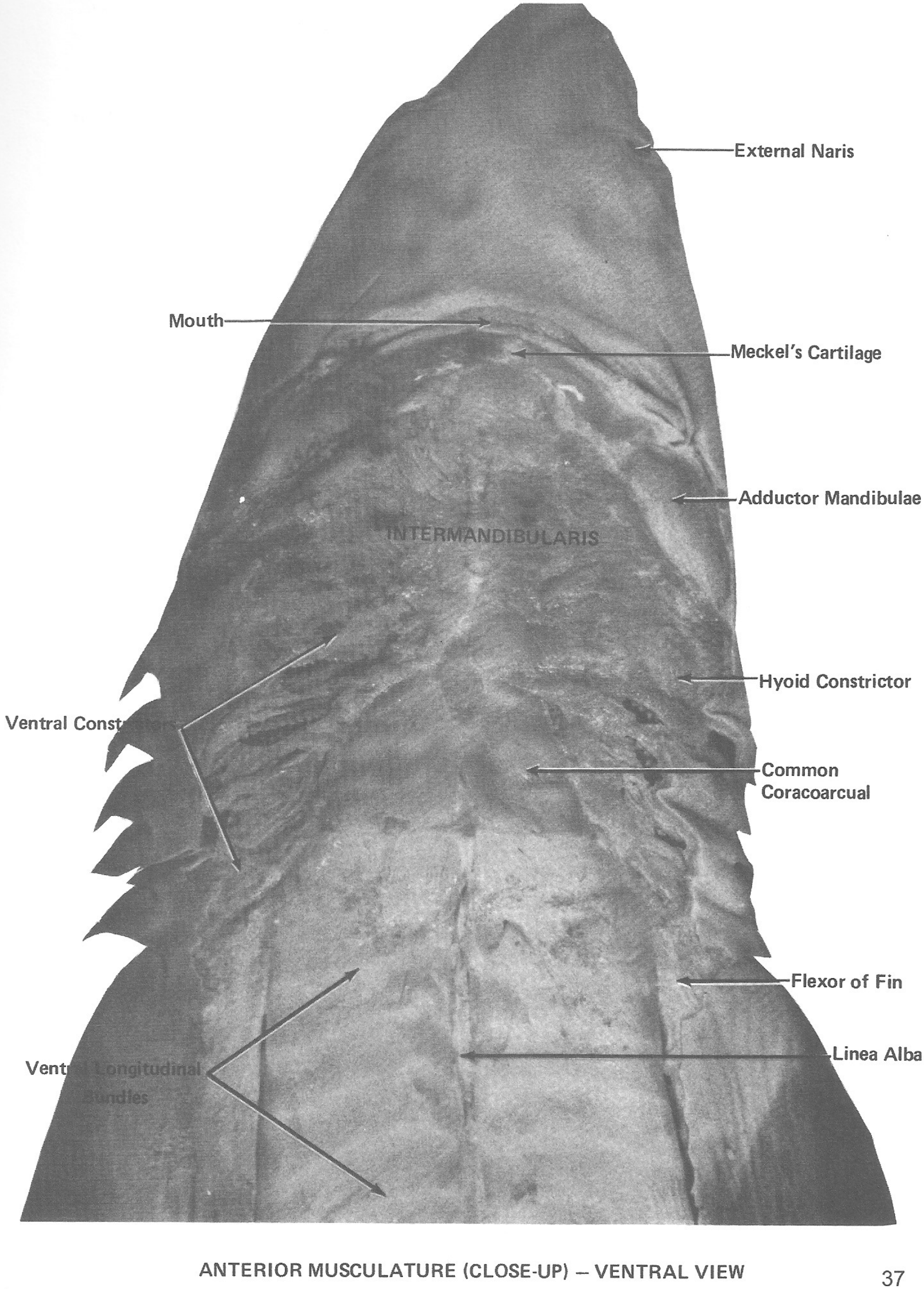
The dorsal muscle mass, the *extensor,* arises from two origins. The more *superficial extensor* originates from the iliac process of the puboischiae bar, while the *deeper extensor* originates from the metapterygium. Both insert upon the radials and the ceratotrichia.

The muscles of the pelvic fins of males are fundamentally the same as in females. However, some portions of the dorsal and ventral muscle mass extend into the male's clasper as separate muscles. Also, in the male pelvic fin the ventral flexor cannot be fully exposed until a long muscular sac, the *siphon,* is reflected.

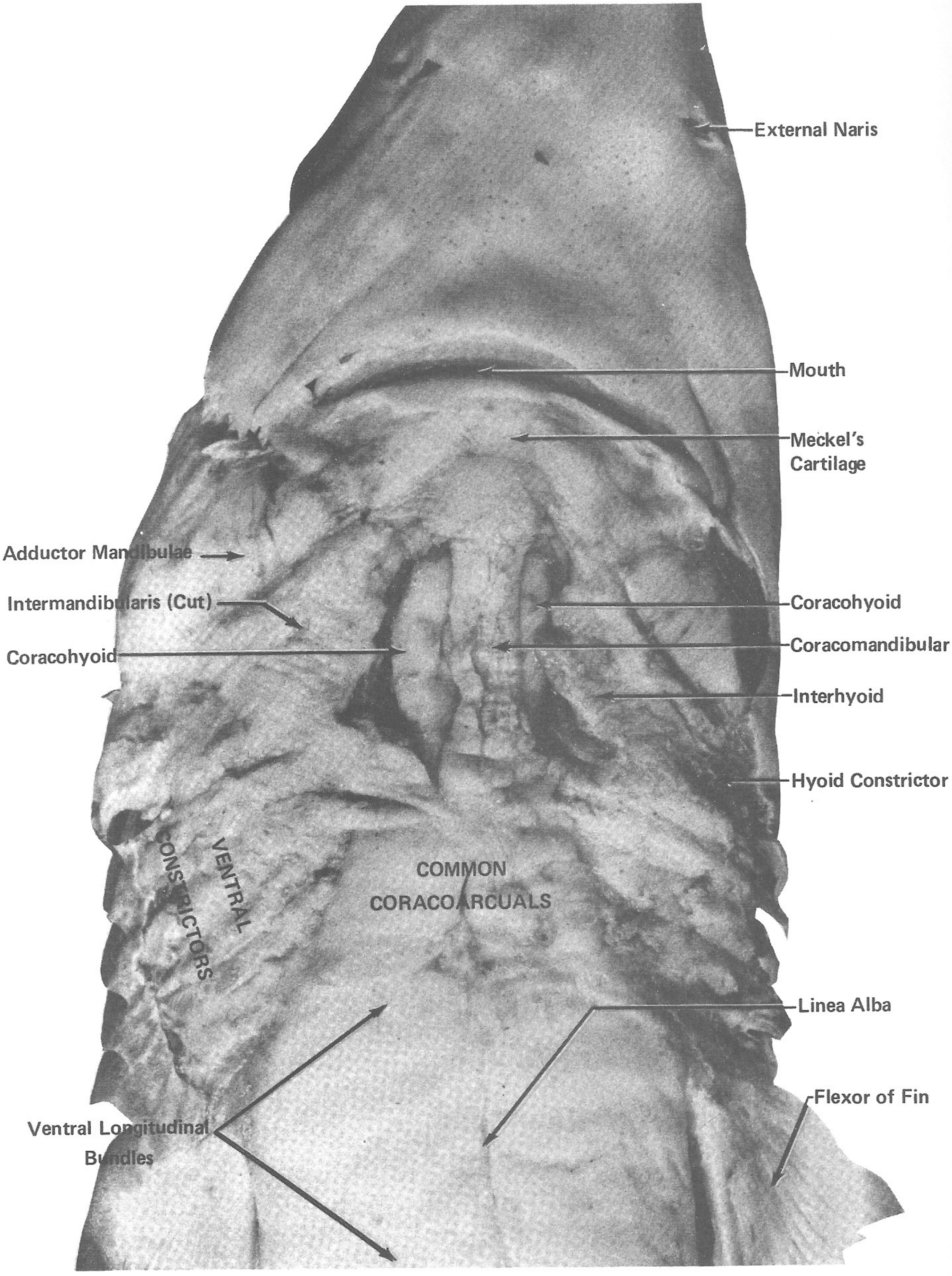
DORSAL FINS — Although these fins are not ordinarily considered appendicular or movable, they possess *radial muscles* upon their sides.



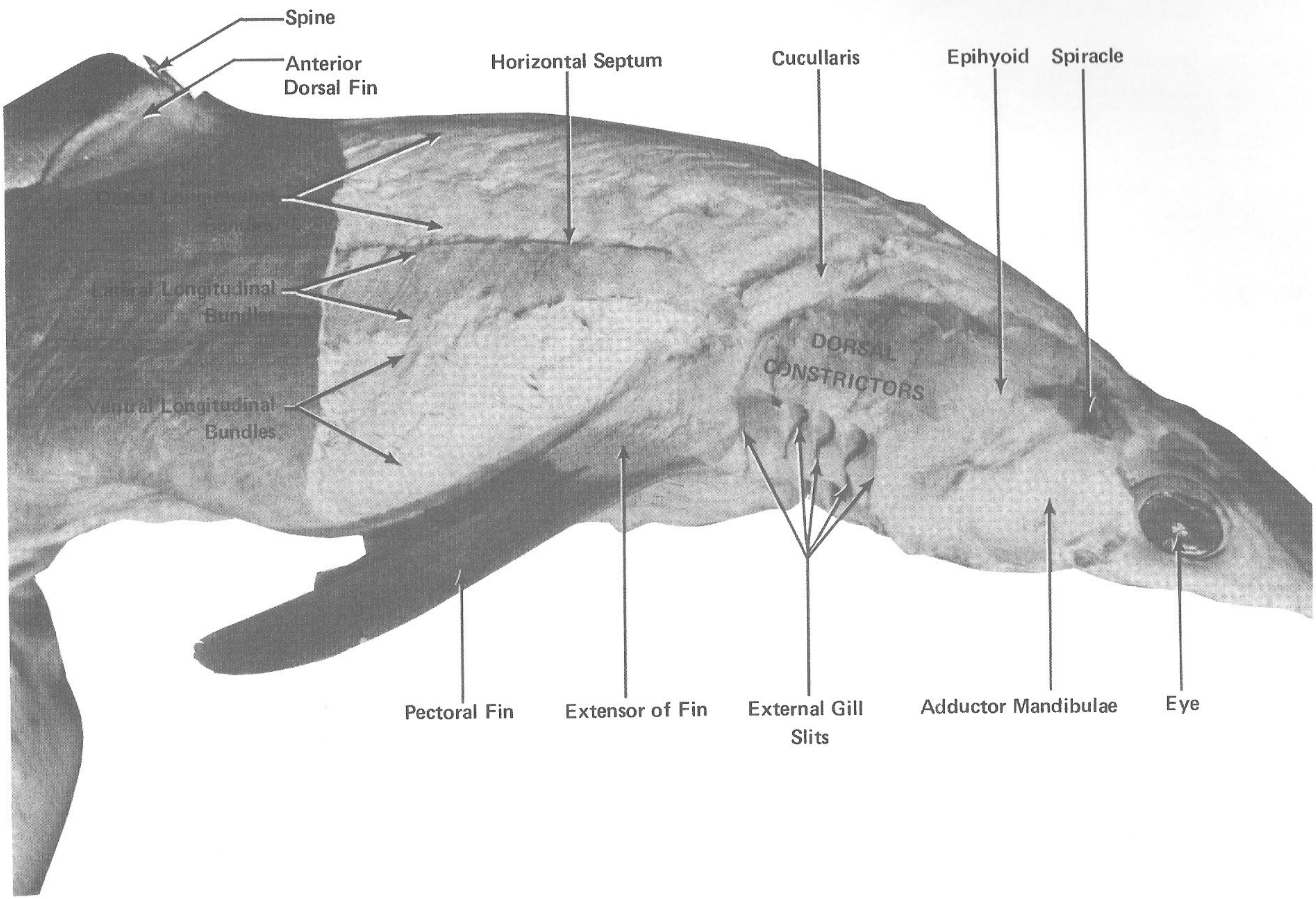
ANTERIOR MUSCULATURE – VENTRAL VIEW



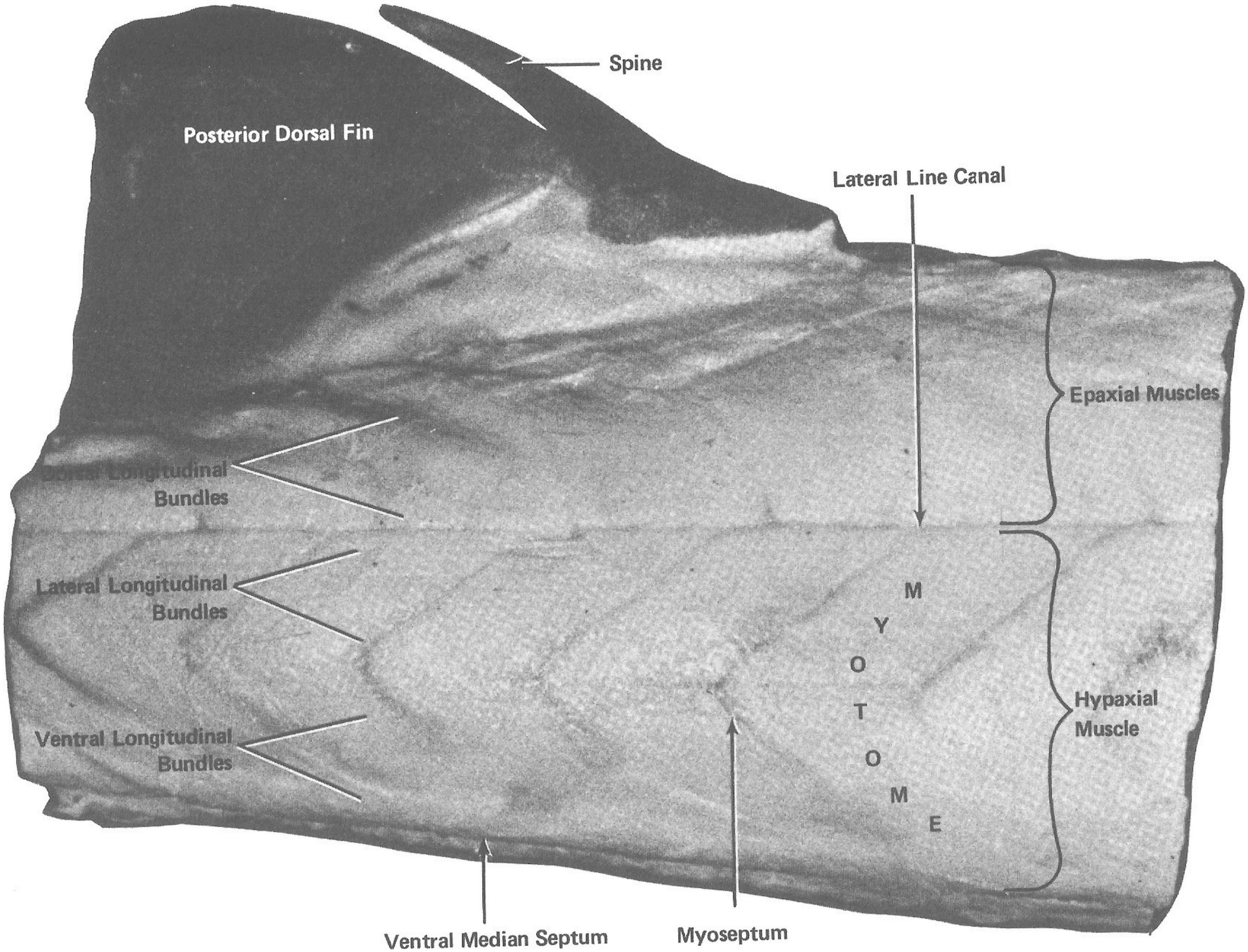
ANTERIOR MUSCULATURE (CLOSE-UP) – VENTRAL VIEW



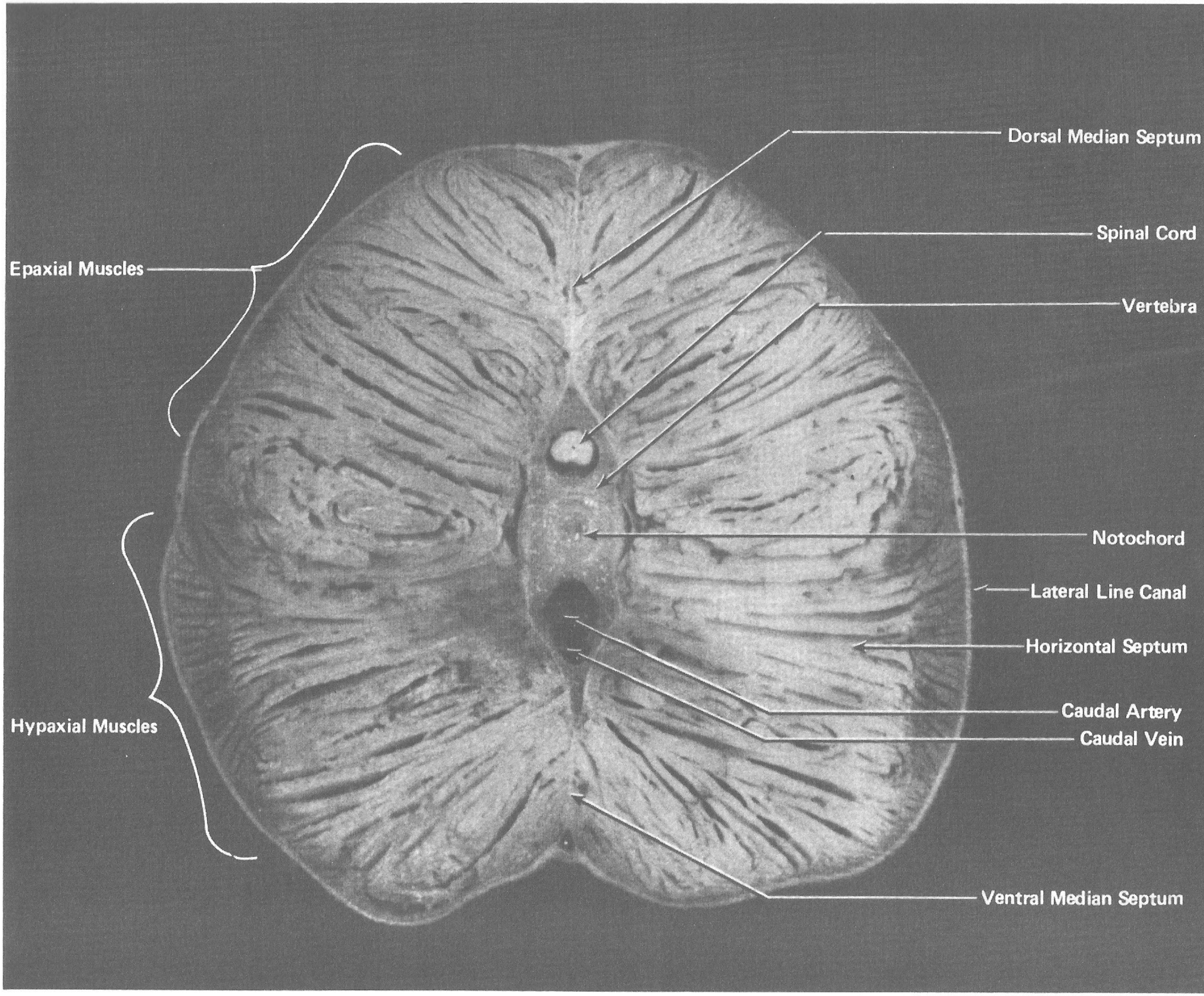
ANTERIOR MUSCULATURE, DEEPER MUSCLES — VENTRAL VIEW

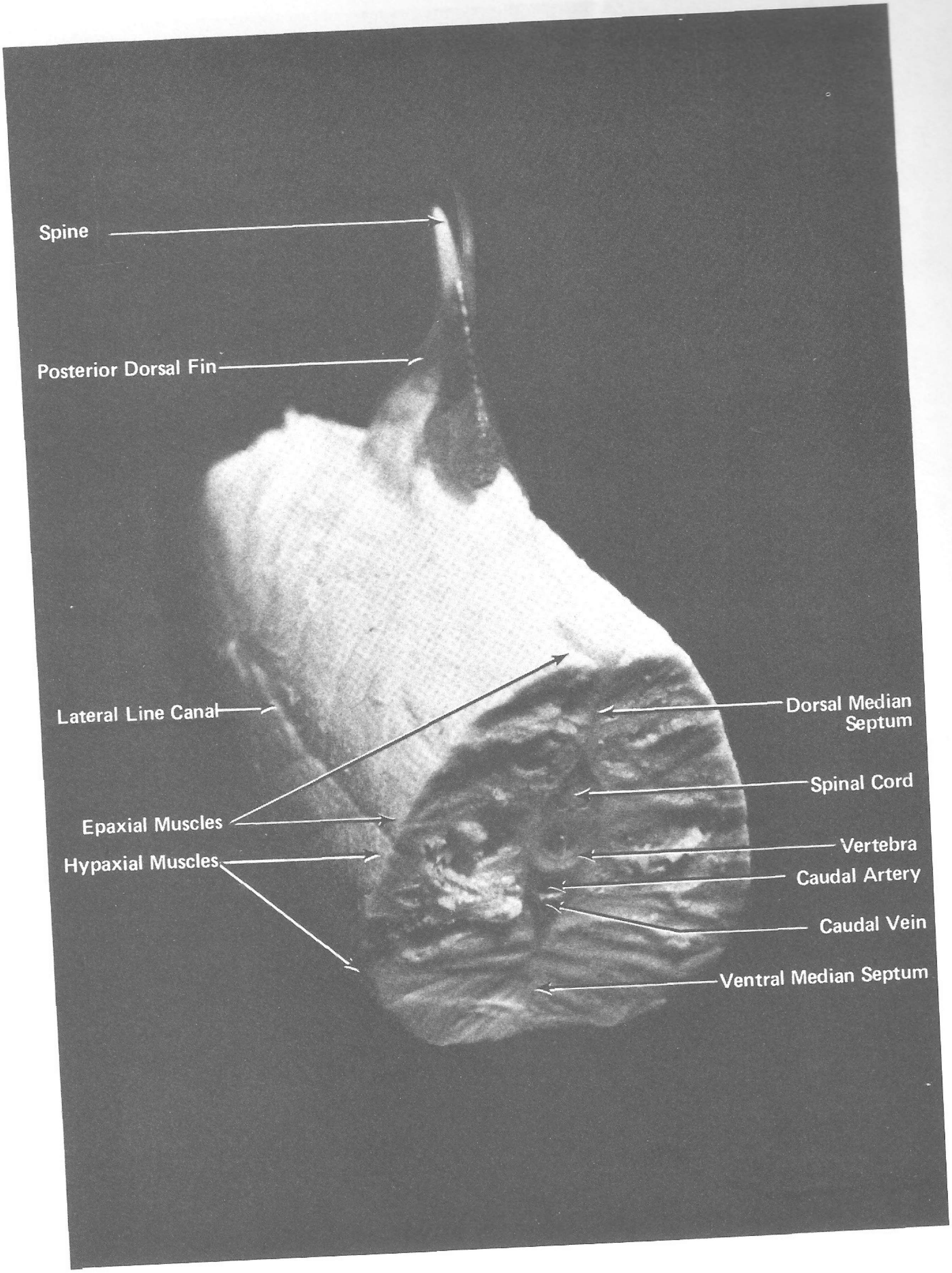


ANTERIOR MUSCULATURE – LATERAL VIEW



POSTERIOR MUSCULATURE – LATERAL VIEW


Dorsal Median Septum
Spinal Cord
Vertebra
Epaxial Muscles
Notochord
Lateral Line Canal
Horizontal Septum
Hypaxial Muscles
Caudal Artery
Caudal Vein
Ventral Median Septum



POSTERIOR MUSCULATURE – STEREOSCOPIC VIEW