GEORGE C. KENT

ANATOMY OF THE VERTEBRATES

A LABORATORY GUIDE

THIRD EDITION

THE C. V. MOSBY COMPANY

Anatomy of the vertebrates

A LABORATORY GUIDE

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THIRD EDITION

with 109 *illustrations*

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Preface

This manual is designed for 84 hours of laboratory instruction. Its predecessor, *Practical Anatomy of the Dogfish, Necturus, and Cat*, was first published in 1949, and since that time the procedures have been continuously tested by thousands of students and revised in accordance with classroom experience.

The organismal approach is used. The initial dissections, after an introduction to protochordates and agnathans, are on a shark and necturus. Then follows dissection of a mammal (cat or rabbit) on a *regional* basis —abdomen, forelimb, thorax, neck, and head—the approach used in most medical and dental schools. The organismal approach enables students to visualize an organism as a *structural and functional entity* rather than as a collection of systems.

Bony fish, anurans, apodans, reptiles, and birds are also studied. The section on bony skulls includes ganoids, crocodilians, and turtles. The section on skin includes scales of ganoids and modern teleosts, dermal bone in reptiles and mammals, and a wide variety of adaptations of the stratum corneum from reptilian scales to baleen.

Suggested demonstrations that students may examine at their convenience have been provided for possible course enrichment. They are not essential. A list of supplies needed for these is on p. 1. Many of the demonstrations are accompanied by a symbol such as **K**195. This means that on p. 195 of the textbook *Comparative Anatomy of the Vertebrates*, fourth edition, by the author of this manual, there is an illustration that may be substituted for the demonstration.

Illustrations are provided only to decrease the time needed for identifying parts that have already been dissected and not for guidance during actual dissection. Dissection should be an adventure—a process of exploration and discovery—and not an exercise in confirming a picture. It is hoped that students will concentrate on the specimen and not on a picture until the dissection is complete.

Increased recognition of the importance of the nervous system in homeostasis dictates that it not be neglected for lack of time. For this reason the muscles of the posterior limb of mammals have been omitted.

The illustrations are the work of numerous individuals. Skeletal drawings are chiefly the work of G. V. S. White and Alison Hanson, to whom I am especially indebted.

George C. Kent

Contents

Suggestions to the instructor

It is not essential that all students have doubly injected specimens. Many instructors order only a percent of their specimens doubly injected.

Biological supply houses make a conscientious effort to supply approximately equal numbers of animals of both sexes. Some disproportionate representation of sexes in a laboratory is usual. Should an undesirable excess of one sex accumulate, it would be well to order a specified number of the opposite sex to reestablish a reasonable ratio.

Supply houses are anxious to provide what the instructor requires. Knowing your specific needs and constructive criticism of specimens supplied will assist them in providing you with the most suitable teaching materials. For example, on arrival of a shipment of slides, each slide should be inspected, and any that are not of the quality that you expect should be returned.

SHARK

One pregnant shark should be ordered for every eight students. Doubly injected sharks are not always satisfactory and are often considered unnecessary. A single specimen injected in the hepatic portal system would be useful but is not essential.

Shark skulls with gill arches are often inadequately prepared. When the hyomandibular cartilages are not clearly identifiable, the ligaments have not been adequately removed. Such a preparation should be returned to the supply house with an explanation of what you expect. Issue of plastic embedded shark neurocrania without gill arches in addition to skulls with gill arches in museum jars will prove economical over the years.

NECTURUS

Dissections of necturus, properly supervised, are meaningful. However, they are frequently less rewarding to students than the instructor would like them to be. To minimize frustration, it would be appropriate to buy the largest available necturuses and to compensate for the higher cost by frugality elsewhere in the course.

CAT OR RABBIT

One pregnant specimen should be ordered for every eight students. After being issued, each specimen should be wrapped in moistened cheesecloth and stored in a cool place. Throughout the laboratory period all parts of the specimen except the immediate region under dissection should be kept covered with moist cheesecloth. After the first few periods it will be necessary to moisten dissected parts (not the skin) during laboratory periods.

Water should never be used on an embalmed mammal. A suitable moistening agent, such as that given below, keeps tissues pliable and should be available at all times. Polyethylene bottles with a few small holes in a tight-fitting screw cap are suitable for sprinkling (not drenching) specimens.

Solution for moistening embalmed specimens

Water	1000 ml
Glycerin (commercial grade)	125 ml
Concentrated liquid phenol (carbolic acid crystals that have taken on water)	30 ml

CHECKLIST OF OPTIONAL DEMONSTRATION MATERIALS

Asterisks (*) indicate items that should, perhaps, have higher priorities. Items are listed in order of appearance in manual.

AMPHIOXUS AND THE PROTOCHORDATES

Amphioxus, large, in plastic; oral hood well preserved, notochord prominent
***Amphioxus**, larval, intestinal cecum not yet obscured by gills
***Sea squirt**, adult (*Ciona, Molgula*)
Enteropneust (balanoglossid worm), wet preserved and/or in plastic

AGNATHANS

***Lamprey**, two adults (*Petromyzon*)
Lamprey, adult (*Lampetra*)
Ammocoete larvae; wet preserved specimens often superior to plastic mounts
***Hagfish**, adult

SHARK

***Shark neurocranium**, in plastic, inner ear injected with latex
***Chimaera**, adult
Shark skin mounted, to show scales and pigment cells (could be made by student from shark)
***Shark skin**, embryonic, cross section, to show dermal origin of placoid scale and an enamel organ
Jaws of large shark
***Shark skeleton**, museum preparation
Shark vertebrae, representative sagittal and cross sections of trunk and tail vertebrae, museum preparation
Skeleton of pelvic girdle and fin of male shark, in plastic
Skeleton of pelvic girdle and fin of female shark, in plastic
Eye of owl, and/or **skull of bird**, to show sclerotic plates
Shark neurocranium, unmounted, for making frontal section

NECTURUS

***Bullfrogs**, two, preserved
***Models or charts of urinogenital system of male and female toad** with rudimentary oviducts and uteri in male
***Frog skull**, columella in place

APODAN

Caecilian, wet preserved or in plastic

SKIN

Large ganoid scales or **dried section of garfish skin**
***Ganoid scale**, ground, mounted on slide
***Bone**, ground, histological preparation
Ctenoid scale, mounted
Cycloid scale, mounted
Turtle carapace or **skeleton**
Alligator skin with osteoderms
Armadillo skin
Antler
***Skull of bovine**, true horn removed on one side
***Amphibian skin**, cross section
***Mammalian skin**, cross section, showing hair follicle and glands
Snake skin, discarded molt
Snake rattles
Dried lizard, bird leg, or **rodent tail** to show epidermal scales
***True horn**
***Baleen**
Large feather
Claws, hoofs, beaks of birds
Rhinoceros horn

SKULLS

***Amia skull**, dermal bones removed on one side
***Amia*, neurocranium (chondrocranium)** only, museum specimen
***Amia* skull** with gill arches, dried
Garfish skull
Bullfrog skull, disarticulated, mounted
***Hyoids of frog, reptile, bird, mammal**
Necturus neurocranium (chondrocranium), showing endochondral ossification centers
Necturus skull, disarticulated, mounted
Sea turtle mandible in museum jar or plastic, to show Meckel's cartilage
Turtle skulls, several species, to show varying degrees of palatal evolution; sea turtle plus common snapper would be minimal demonstration
Snake skull
***Alligator skull**, columella present
Kitten skull, showing occipital sutures
***Mammalian ear ossicles**
***Chart or model of human ear**
Cat or rabbit skull, disarticulated, bones labeled and mounted
Human fetal skull, to show fontanels
Temporal bone of man, dissected to show middle ear and ossicles
Temporal bone of man, dissected to show bony labyrinth
Human skeleton with hyoid bone
Separate human occipital, sphenoid, ethmoid, and **temporal bones (neurocranium)**
***Chart or model of human larynx and hyoid**

CAT OR RABBIT

Cecum of rabbit, or **other herbivore,** to show appendix
***Fetal pigs,** arteries injected
Chart of human digestive tract
Uteri (bipartite, bicornuate, simplex), museum preparations
***Placentas** of following types, museum preparations:
Discoidal (rabbit and/or man)
Cotyledonary (sheep)
Zonary, if cat is not being dissected
Chorionic sacs of pig to demonstrate diffuse placenta (one sac should be opened to reveal fetus in amnion); pregnant hamsters or rats may be used to demonstrate distribution of conceptuses in uterine horns
Chart of human heart opened
Heart of large mammal
Cat or rabbit brain and **spinal cord;** student could prepare one
Sheep, cow, human, other mammalian brains

CHECKLIST OF NONEXPENDABLE MATERIALS

This checklist includes only those nonexpendable materials that may be issued to students.

Amphioxus, large preserved
Amphioxus, large, in plastic; head region to show clearly velum, wheel organ, velar tentacles
Amphioxus, microscope slide, representative cross sections; in ordering, specify that pharyngeal sections include intestinal cecum and gonad (or, order separate slide of pharyngeal level that includes cecum and gonad)
Shark skulls with gill arches, in fluid-filled sealed museum jars; specify that the hyomandibular cartilages be thoroughly cleaned and identifiable; plastic embedded preparations are usually inferior as a teaching aid
Shark neurocrania (chondrocrania), opaque, in plastic; specify that the *two* foramina in lateral wall of endolymphatic fossa be clearly distinguishable and olfactory capsules be reasonably represented
Necturus skulls with gill cartilages, in fluid-filled museum jars; specify that ceratobranchial and epibranchial cartilages be identifiable
Whole skulls as follows: bullfrog, necturus, alligator or caiman, cat or rabbit
Bullfrog skulls, disarticulated, unmounted
Cat or rabbit skulls, disarticulated, unmounted
Cat or rabbit skulls, bisected
Human skulls, calvaria removable
Cat or rabbit skeleton, mounted
Watch glasses and **hand lenses**
Dissecting microscopes to extent practicable
Compound microscopes with low power lenses will be essential during study of amphioxus

For valuable suggestions in the preparation and use of anatomical demonstrations, the following is suggested:

Hildebrand, M.: Anatomical preparations, Berkeley, 1968, University of California Press.

TO THE TEACHING ASSISTANT

Dissection should be an interesting and challenging *adventure* in a relaxed, cordial, but orderly environment, to which motivated students look forward with pleasant anticipation. A skilled laboratory instructor criticizes constructively and complements or challenges each student in accordance with the student's individual potential for achievement. The instructor constantly moves about the room observing the progress of individual dissections, making unsolicited pertinent suggestions, occasionally posing thought questions (subject to approval of the faculty member in charge), and offering help. Sometimes a student's question is best answered by asking a related one. Effort expended in enthusiastic laboratory instruction will be amply repaid in respect and gratitude. A laboratory instructor must be thoroughly cognizant of the problems that the coming dissection may pose. If he has not recently instructed in such a lab, he should perform the dissection himself, completely, in advance. Undergraduate students quickly recognize capabilities or inadequacies of teaching assistants, even though they are unlikely to express their opinions.

LEARNING PLATEAU

Most undergraduate students reach a plateau in interest and in the acquisition of skill in dissection after 4 or 5 weeks of laboratory work. This is a normal phenomenon and one that the experienced instructor will detect when it occurs. The symptom is a decrease in the rate of dissection—an unintentional tendency to accomplish less in a given laboratory period. If students are apprised of the

plateau when it is reached, their rate of progress will again accelerate.

DISSECTING INSTRUMENTS

Each student, or each pair at least, should have a scalpel with replaceable snap-on blades, several reserve blades, a probe, fine and coarse forceps, and a pair of sharp, small scissors. Additional instruments would be useful but are not required unless the instructor directs otherwise.

Terms of direction and position

Bilaterally symmetrical animals have three body axes: *longitudinal*, *right-left*, and *dorsoventral*. Any two axes establish a plane. *Transverse planes* are established by the dorsoventral and right-left axes. Sections cut in these planes are *cross sections*. *Frontal planes* are established by the longitudinal and right-left axes. Cuts in these planes are *frontal sections*. The *sagittal plane* is established by the longitudinal and dorsoventral axes. A cut in this plane is a *sagittal section*. Any number of parasagittal sections may be cut parallel to the sagittal plane. Outside of class, apply these concepts to a fish, a cat, and man.

Study the following terms so that you understand them and can use them to express anatomical relationships.

dorsum (n.)	upper side of an animal or organ; the back.
dorsal (adj.)	pertaining to the dorsum.
dorsad (adv.)	toward the dorsum.
venter (n.)	underside of an animal or organ; the side opposite the dorsum.
ventral (adj.)	pertaining to the venter.
ventrad (adv.)	toward the ventral region.
lateral (adj.)	lying at the right or left side.
laterad (adv.)	toward the side.
median (adj.)	in the sagittal plane, hence unpaired.
medial (adj.)	same as median.
mediad (adv.)	toward the sagittal plane.
anterior (adj.)	pertaining to the head end; in man, sometimes equivalent to ventral.
posterior (adj.)	pertaining to the end opposite the head; in man, sometimes equivalent to dorsal.
cranium (n.)	the skull.
cranial (adj.)	pertaining to the skull.
craniad (adv.)	toward the skull.
cephalon (n.)	the head.
cephalic (adj.)	pertaining to the head.
cephalad (adv.)	toward the head.
cauda (n.)	the tail.
caudal (adj.)	pertaining to the tail.
caudad (adv.)	toward the tail.
proximal (adj.)	refers to a position next to or close to a point of origin or reference.
distal (adj.)	opposite to proximal.
distad (adv.)	toward the distal region.
superficial (adj.)	on or near the surface; not deep.
superior (adj.)	used in man to refer to the upper parts of the body.
inferior (adj.)	used in man to refer to the lower parts of the body.

1

Amphioxus
AND THE PROTOCHORDATES

The amphioxus (*Branchiostoma*, subphylum Cephalochordata) is studied as an introduction to vertebrates because it exhibits certain characteristics seen also in vertebrates. Chief among these are the *dorsal tubular nervous system*, the *notochord*, and the *paired slits (pharyngeal slits)* in the wall of the digestive tract.

Whole preserved specimen (Fig. 1-1)

With the aid of a hand lens or dissecting scope, study the external anatomy of a large specimen preserved in fluid.

At the anterior end a delicate membrane, the *oral hood*, hangs down on each side to form a *vestibule* that is open ventrally. Fringing the free borders of the oral hood are tentacle-like *buccal cirri* (sing. *cirrus*) containing chemoreceptors. A series of <-shaped muscle segments (*myomeres*) extends the length of the body. Separating the myomeres and serving as their origins and insertions are connective tissue *myosepta*. A pair of ventral *metapleural folds* (better seen on cross sections) commence near the anterior end and pass caudad to converge immediately behind a small excurrent aperture, the *atriopore*, located about three fourths of the way back. Serially arranged blocks of *gonads* can be seen through the ventrolateral body wall.

Demonstration

Large amphioxus embedded in plastic and stained to show notochord and other details. Observe under a dissecting scope.

Mounted small specimen (Figs. 1-2 and 1-3)

Do not use the high power of a compound microscope. You will crush the cover slip. A dissecting scope would be ideal.

The *alimentary canal* should be easily seen. The *pharynx* is that part of the alimentary canal perforated by *gill slits* separated by *gill bars*. The remainder of the alimentary canal is the *intestine*, terminating at the *anus*. From the intestinal floor just behind the pharynx a club-shaped *intestinal cecum* extends forward on the right of the pharynx. Careful focusing will reveal the cecum partly obscured by the gills. The cecum secretes

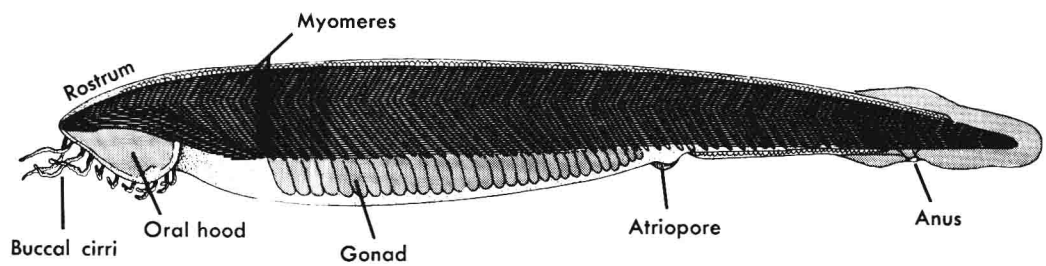

Fig. 1-1. Adult amphioxus.

enzymes and phagocytoses food particles that are swept into it. Caudal to the cecum is a muscular *midgut ring*. It causes some foodstuffs to back up into the cecum for digestion.

Demonstration

Young amphioxus with few gill slits showing that the cecum arises as a forward-directed bud from the floor of the anterior end of the intestine, as does the vertebrate liver (Fig. 1-2).

The notochord is dorsal to the alimentary canal. Dorsal to the notochord is the neural tube *(central nervous system)* made up of *brain* and *spinal cord*. The brain commences at a pigment spot (Fig. 1-3). Anterior to the brain is a *rostrum* into which the notochord extends. (In vertebrates the notochord commences at the midbrain.) Where the brain ends and the spinal cord begins is not known. The spinal cord is partially obscured on your slide by myomeres, but its position is revealed by the line of pigmented photoreceptive cells *(ocelli)* embedded within its ventrolateral walls.

If the following structures of the head are not clear on your slide, look for another, or for a demonstration slide, and consult Fig. 1-3. Observe the buccal cirri and oral hood. Forming the posterior wall of the vestibule is a perpendicular membrane, the *velum*, perforated by the *mouth*. (The mouth cannot be seen from this angle. It leads into the pharynx.) A wheel organ and velar tentacles extend into the vestibule from the velum. The *wheel organ* is a set of blunt, finger-like projections that creates a current of water and food through the mouth and into the pharynx. The *velar tentacles* are chemoreceptors.

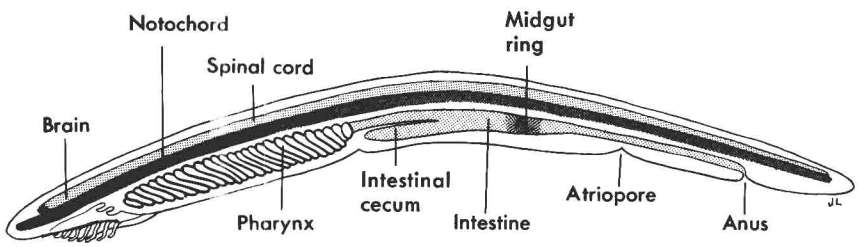

Fig. 1-2. Internal structure of a young amphioxus.

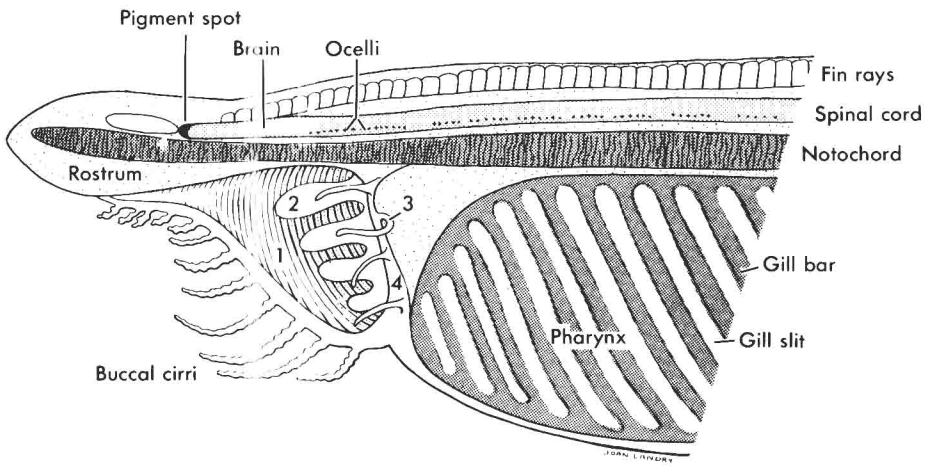

Fig. 1-3. Head end of amphioxus. **1,** Vestibule bounded laterally by oral hood; **2,** part of wheel organ projecting into vestibule; **3,** velar tentacle attached to velum and projecting into vestibule; **4,** velum.

Cross section through pharynx
(Fig. 1-4)

With the *lowest magnification* of a compound microscope or with a dissecting scope identify the following.

Pharynx. Account for the fact that many gill bars appear in one cross section. The ciliated *hypobranchial groove* in the pharyngeal floor secretes mucus that traps food particles. The mucus is swept dorsally by cilia on the inner surface of the gill bars to the *epibranchial groove* and from there into the intestine.

Atrium. The atrium is a chamber surrounding the pharynx laterally and ventrally and opening to the outside by an atriopore. The water in the pharynx passes through gill slits, where it is aerated, and into the atrium.

Notochord. Surrounded by a notochord sheath.

Spinal cord. Dorsal to notochord.

Intestinal cecum. A hollow diverticulum of the gut to right of pharynx. Only by examining a stained, whole mount of an amphioxus can you verify that the cecum is on the right. Why?

Gonads. Testes may be identified by presence of sperm tails; ovaries by ova with large nuclei.

Paired aortas. The dorsal aorta is paired above the pharynx. It collects aerated blood from the gills.

Body wall. Observe myomeres laterally and thin transverse muscle band ventrally. The body wall is covered by a two-layered skin.

Metapleural folds. Inconspicuous longitudinal ridges on each side of midventral line. They commence at the cephalic end of the pharynx and end at the atriopore. Their function is unknown.

Cross sections anterior and posterior to pharynx

How many structures identified earlier can you recognize in these sections?

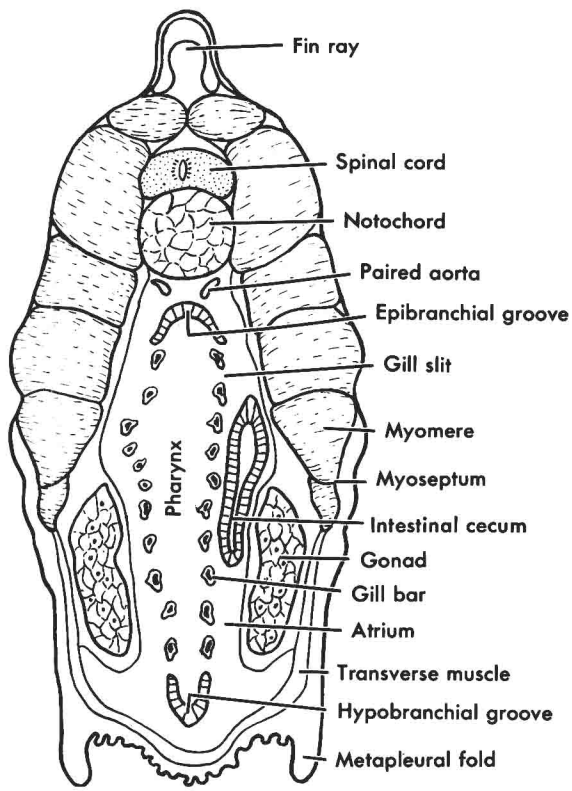

Fig. 1-4. Cross section of amphioxus near caudal end of pharynx, caudal view.

OTHER PROTOCHORDATES

Demonstrations

1. Adult sea squirts (subphylum Urochordata). One or more species (*Ciona, Molgula, Styela,* etc.) may be on demonstration. Adults are sessile and lack a notochord, but the free-swimming larva has a notochord confined to the tail. The body is covered by a tough cellulose-like tunic. **K**21, **K**23*

2. An enteropneust. These worms are sometimes classified as chordates in a subphylum Hemichordata. The animal on display may be either *Balanoglossus* or *Dolichoglossus*. **K**31

*The symbols indicate that appropriate illustrations of this demonstration appear on pp. 21 and 23 of the companion textbook: Kent, G. C.: Comparative anatomy of the vertebrates, ed. 4, St. Louis, 1978, The C. V. Mosby Co.

2

Agnathans
THE LOWEST VERTEBRATES

LAMPREY
External anatomy and skin

The specimen may be *Lampetra*, a small freshwater lamprey, or *Petromyzon*, a larger marine lamprey. There are no paired appendages, no scales, no jaws, and no bone. A *buccal funnel* with horny epidermal teeth leads to the mouth. Seven *gill slits* lead to gill pouches. A single *naris* is on the middorsal line of the head. It opens into a nasal canal that leads to an olfactory sac and then ends blindly in a nasohypophyseal sac (Fig. 2-1,*B*). Posterior to the naris is an unpigmented spot of skin, the *pineal cornea*, beneath which is the pineal eye. **K**401*

In the midventral line a shallow pit, the *cloaca*, marks the junction between trunk and tail. The cloaca receives the intestine and exhibits a *urinogenital papilla* that discharges urine and sperm or eggs.

On a specimen from which several centimeters of skin have been removed, observe the *myomeres* (muscle segments) separated by *myosepta*. **K**214 Examine a section of skin. It consists of a glandular *epidermis* and a dark, tough, fibrous *dermis* that adheres closely to the underlying myomeres and myosepta.

Internal anatomy

Head and pharynx. On a sagittal section, identify the structures in Fig. 2-1, *B*. To make your own preparation, wedge the specimen dorsal side up between two wooden blocks or other vertical supports, use a sharp knife with a long blade (15 or 20 cm is optimal), and make as perfect a midsagittal section as you can. Cut with firm downward pressure, avoiding sawlike movements. Stop cutting about 6 cm behind the last gill slit.

Coelomic viscera. Make a midventral longitudinal incision into the coelom from pharynx to cloaca. The heart occupies the *pericardial cavity*, one of two subdivisions of the coelom. The remaining viscera occupy the *pleuroperitoneal cavity* and may be identified with the aid of Fig. 2-1. Locate the *esophagus*, the large *liver*, the long straight *intestine*, which is dorsal to the liver and then lies ventrally caudal to the liver (there is no stomach), and the large unpaired *gonad* that nearly fills the pleuroperitoneal cavity and has a dorsal mesentery. There are no genital ducts. Sperm and eggs are discharged into the pleuroperitoneal cavity and enter paired *genital pores* at the extreme end of the cavity. The pores open into the urinogenital sinus. The two kidneys (*mesonephroi*, or *opisthonephroi*) are long thin flaps that hang from the dorsal wall of the cavity. Along the free border of each kidney is a kidney duct. The two ducts unite caudally to empty into the urinogenital papilla.

Make a cross section of the dorsal half of the trunk just behind the heart and identify the notochord, spinal cord within a fibrous neural sheath, and the unpaired dorsal aorta between two postcardinal veins (Fig. 2-1, *A*) in the roof of the pleuroperitoneal cavity.

Lateral neural cartilages. The only structures resembling vertebrae are paired lateral neural cartilages. To observe one, remove a section of the back about 3 to 4 cm long containing notochord and spinal cord, and dissect to locate delicate vertical cartilages that lie immediately lateral to the fibrous sheath surrounding the spinal cord. The cartilages

*See footnote on p. 9.

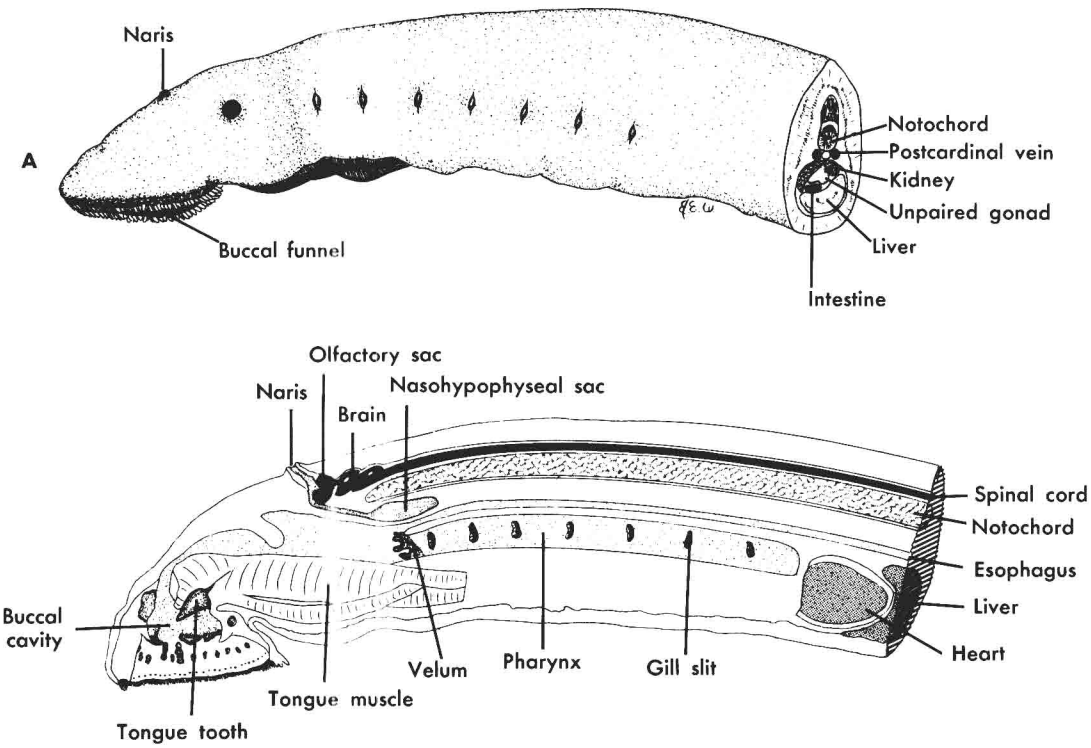

Fig. 2-1. Cephalic end of the lamprey *Petromyzon*. **A,** External features and cross section. **B,** Sagittal section.

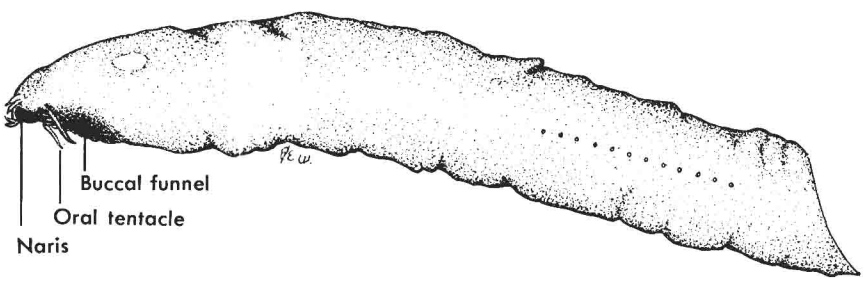

Fig. 2-2. Head end of hagfish *Bdellostoma stouti*.

resemble neural arches that lack centra and do not meet dorsally. **K7**

Larval lamprey K19, K33

Preparations of larval lampreys (ammocoetes) may be available. Compare their major features with those of the amphioxus.

HAGFISH

The specimen may be *Myxine* or *Bdellostoma*. In *Myxine* the gill pouches open externally by a single pair of *branchial pores*, whereas those of *Bdellostoma* open separately (Fig. 2-2). The left pore of *Myxine* is usually larger because it receives a pharyngocutaneous duct. **K261** The eyes are vestigial and functionless. The cloaca is like that of a lamprey. Compare the location of naris and appearance of buccal funnel with those of a lamprey. In hagfishes the nasal canal extends beyond the olfactory sac and opens into the pharynx.