Introduction to Chordates & Fish Anatomy

Biology 6A / Sanhita Datta
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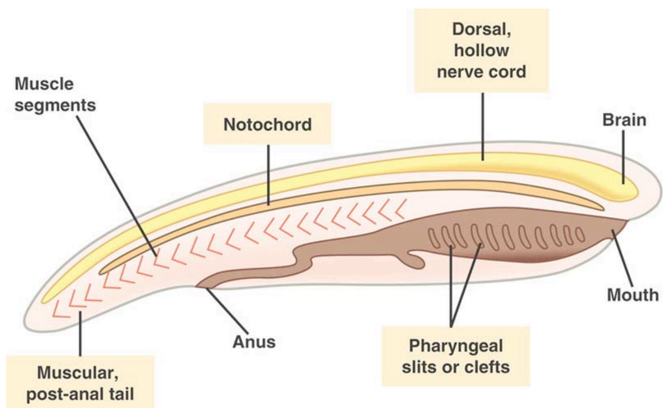
Today's lab has two parts:

- **Introduction to Chordates:** an introduction to the key characteristics of the phylum Chordata, with just a few specimens to study.
- **Fish anatomy:** dissection of some fresh fish in order to learn their external and internal anatomy.

The next two labs will also be dedicated to this phylum: one lab for mammalian anatomy as seen in fetal pigs, and one lab for vertebrate skeletons.

Chordate characteristics



TISSUES:	•	Three well-defined tissue layers in embryo.
SYMMETRY:	•	Bilateral, with cephalization.
BODY CAVITY:	•	Coelom
PROTO/DEUTEROSTOME:	•	Deuterostome: the blastopore formed during gastrulation eventually becomes the anus; the mouth forms later.
DIGESTIVE TRACT:	•	Complete digestive tract.
CIRCULATORY SYSTEM	•	Closed in vertabrates; open in a few others.
OTHER FEATURES	•	Segmented body. Vertebrae, for example.
	•	Endoskeleton
	•	Notochord: a connective-tissue body stiffener
	•	Dorsal tubular nerve cord – forms brain and spinal cord.
	•	Pharyngeal pouches and slits – gill related structures that may appear and then disappear early in development.
	•	Postanal tail. In many worms, the anus is at the very tip end of the animal's body; chordates typically have a tail beyond the anus.

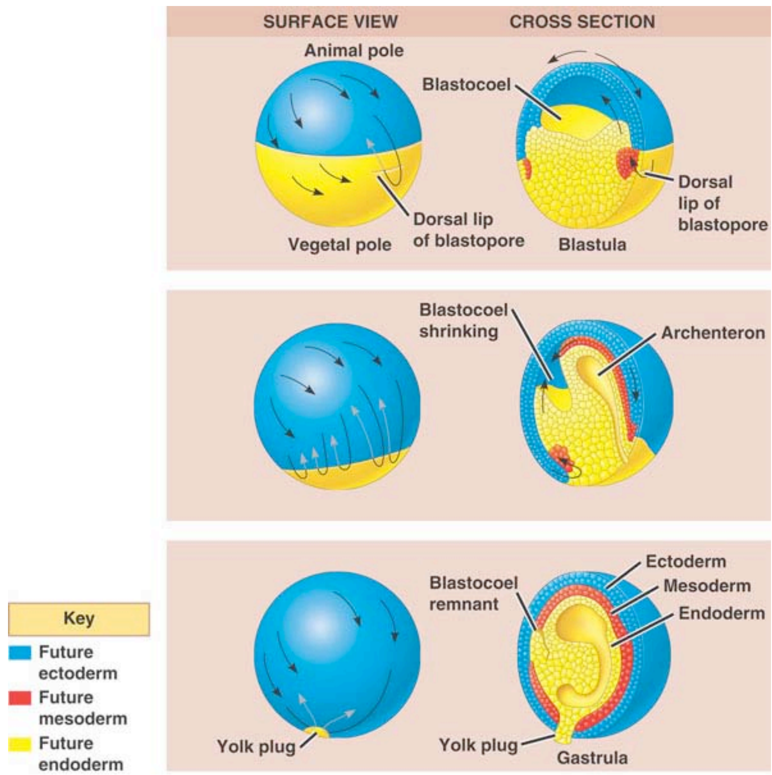
Early development of chordates

The defining features of chordates appear early in development.

Gastrulation

Like other animals, chordates progress through blastula and gastrula stages. Gastrulation not only forms the beginning of the digestive tract, it also forms the three embryonic tissue types: endoderm, mesoderm, and ectoderm.

The diagram at right shows gastrulation in a frog. The process is somewhat similar to gastrulation in echino-derms (as shown in last week's handout on animal tissues and development). However, chordate gastrulation is somewhat more complex, partly because the early embryo is more asymmetrical and more filled in with cells.



Chordates are **deutero-stomes**. This means that the blastopore (the opening into the archenteron that forms during gastrulation) becomes the anus; the mouth forms later. Echinoderms are also deuterostomes, but annelids and arthropods are protostomes. In those phyla, the blastopore becomes the mouth, and the anus forms later. This is one of the reasons that chordates are considered to be more closely related to echinoderms than to arthropods.

Notochord formation

The notochord, one of the unique defining characteristics of chordates, is a semi-stiff rod of connecting tissue that forms in the embryo and to guide the development of the vertebral column (backbone) of vertebrates, along with other structures. In your own body, the notochord has mostly disappeared; the only remnants are the cartilaginous disks between your vertebrae

Neurulation

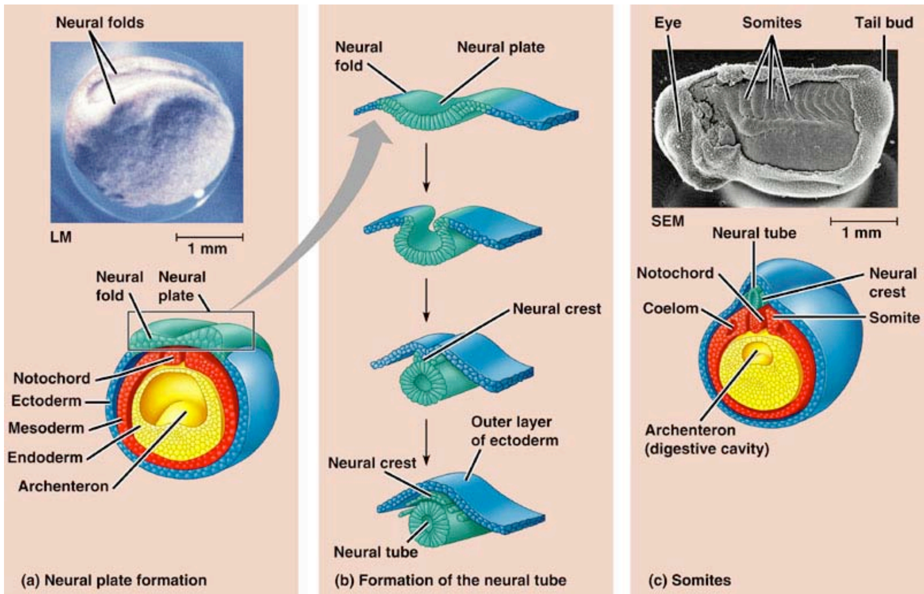
Neurulation forms the **dorsal hollow nerve cord** in a developmental event that bears some resemblance to gastrulation. The dorsal hollow nerve cord is another unique feature of chordates.

Following gastrulation, the presence of a notochord induces **neurulation** of the overlying dorsal ectoderm. This third stage of morphogenesis is unique to chordates. The ectoderm above the notochord thickens to form the neural plate. This plate then invaginates to form a furrow along the anterior-posterior axis. The folds along the groove eventually seal over the furrow to form the

neural tube that in turn develops into the **dorsal hollow nerve cord**. This nerve cord eventually develops into the central nervous system, including the spinal cord and brain.

By contrast, in non-chordate animals the main nerve cord is solid and usually ventral.

The diagram below (fig. 47.14 from Campbell) shows neurulation and associated events in a frog.



Chordate development specimens:

- **Models of frog development & neurulation.** Note the stages of development following gastrulation. Identify the subsequent appearance of the **notochord**, **neural plate**, and finally the **neural tube** and **neural crest**. Compare to *Campbell* **Fig. 47.14**.
- **Slides of 13-hour & 18-hour developing chick embryos.** Compare the developing chick to the models of frog morphogenesis and identify the corresponding homologous structures named above. Refer to the *Photo Atlas* **Fig. 2.16**.

☛ (CAUTION: We will be examining today several slides of this series showing stages of development in the chick embryo. The slides with the later stages are thick and can only be viewed at low power. Don't break them by using a higher power objective.)

Non-vertebrate chordates: urochordates and cephalochordates

Urochordates and cephalochordates are in the phylum Chordata, but they aren't vertebrates; in fact, you might not immediately recognize them as belonging to your own phylum.

Urochordates (tunicates)

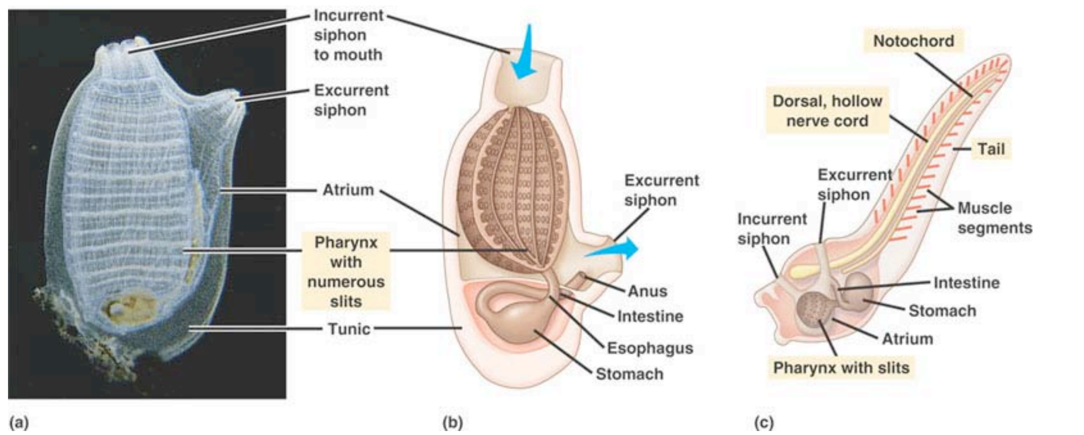
Tunicates (also called sea squirts) are marine suspension feeders. They live in the ocean, pump water though their gut, and capture small particles of food suspended in the water. They are different from vertebrates in many respects:

No cephalization of the dorsal nerve tube – in other words, no brain.

Open circulatory system that can even reverse its direction of flow.

Pharyngeal arches and slits form a ciliated **filter basket** (pharynx) used for gas exchange and suspension feeding. Water is drawn in through an incurrent siphon and pumped out through an excurrent siphon, passing through the slits in the pharynx. A sheet of mucus is used to capture suspended particles. The arches of the pharynx are vascularized, and serve for gas exchange as well as food capture.

Many urochordates are sessile; they spend their adult lives glued to the bottom of the ocean.



The diagram above (fig.34.4 from Campbell shows adult tunicates in (a) and (b), and a larval tunicate in (c).

While urochordates differ from vertebrates in many ways, they also show the defining characteristics of the phylum Chordata, including the notochord, and the dorsal hollow nerve cord.

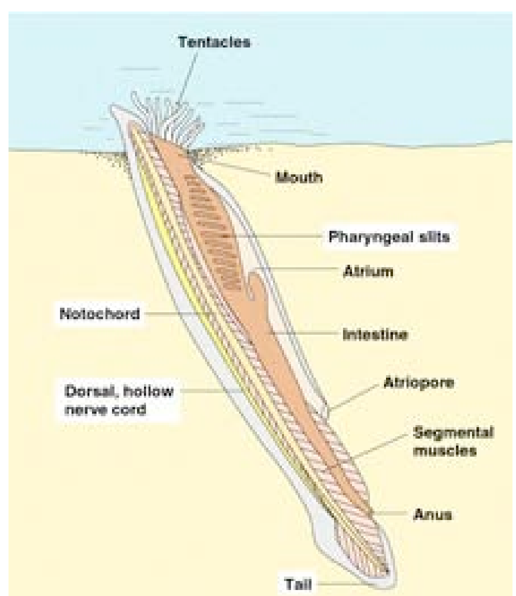
We don't have many urochordate specimens in the lab, but:

- **Preserved specimens of adult ascidians.** Identify the **incurrent siphon**, the **filter basket** formed by the **pharyngeal arches**, the **atrium**, and the **excurrent siphon**. Where is the notochord?

Cephalochordates (Amphioxus, or lancelets)

The lancelets (Class **Cephalochordata**) resemble fish larvae, but they never develop bones. They are chordates, but not vertebrates.

The notochord remains throughout life and serves as a semi-rigid endoskeleton. Mesodermal blocks develop segmented muscle bands called **myotomes**. The atrial aperture (atriopore) is directed posteriorly, and the anus is located outside the atrium posterior to the atriopore. A pre-anal ventral fin and post-anal caudal fin aid mobility as the lancelet burrows tail-down into sandy substrate projecting its oral aperture and ventral filter basket up into the water column.



The diagram at right (fig.34.5 from Campbell) shows most of the features you should be able to see in our microscope slides of a lancelet. Note that there is a pathway that water passes through, called the

atrium; this is separate from the intestine. As water is pumped through the atrium, it is forced through the **pharyngeal slits**, where food particles are captured. The food particles are then passed into the digestive tract.

- **Slides with w.m. & c.s. of the lancelet *Amphioxus*.** Identify the following structures: tentacles, mouth, notochord, dorsal nerve cord, pharynx with slits, atrium, intestine, tail, muscle segments (myotomes).

Vertebrates

The vertebrates (phylum Chordata, subphylum Vertebrata) include fish, amphibians, reptiles (including birds) and mammals. All these animals have the basic characteristics of chordates, with some added twists:

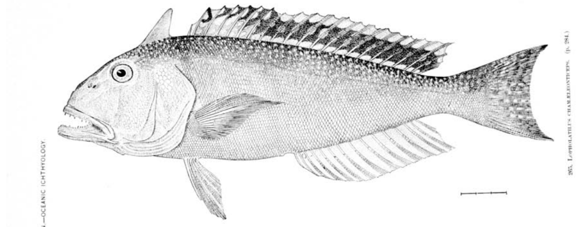
- The anterior region of the **dorsal hollow nerve cord** expands to become a **brain** and is encased within a skeletal **cranium**.
- Mesodermal blocks develop not only **myotomes**, but a **segmented vertebral column** that protects the posterior region of the dorsal nerve cord (**spinal cord**) and replaces the notochord. The cranium and vertebral column comprise the **axial skeleton** of vertebrates allowing an elaborate central nervous system and powerful muscle action with a flexible body.
- The development of a brain has further spurred the development of more sophisticated cephalic sensory organs, especially **eyes, nostrils** and **ears**.
- To support their enhanced homeostasis, vertebrates also have a **closed circulatory system** with distinctive types of heart and kidneys, and a greater suite of endocrine organs.

Vertebrate specimens:

- **Slides of 21-hour through 48-hour developing chick embryos.** Observe the dramatic **cephalization** of the **dorsal hollow nerve cord** with the distinction of **brain** from **spinal cord** and development of cephalic sensory organs, notably the **eyes** and **ears.** Note also the **segmentation** evident in the developing **myomeres**, and the early establishment of the segmented **vertebral column**.
- **Slides of 2-day through 7-day developing chick embryos.** Observe the **limb buds** developing into the appendicular skeleton. Locate each of the four **extra-embryonic membranes** and describe their respective functions. C.f., *Campbell* **Fig. 47.17**.
- **Slide of lamprey ammocoetes larva.** The ammocoete larva of lampreys resembles a lancelet in form and habit, but with the vertebrate modifications described above.How is this larva similar to the lancelet? How is it different? How does it differ from the adult lamprey?
- **Skeleton of a bony fish.** Note the segmented axial endoskeleton. What is the function for the spines protruding from the vertebral segments? Examine the hinged jaw, buccal chamber, and pharynx with gill arches. List and locate the unpaired and paired fins.
- **Skeleton of a shark.** Note the corresponding structures to those listed for the boney fish. How is the shark skeleton different from the boney fish (composition; attachment of fins)?

In a later lab, you'll look at vertebrate skeletons in more detail, contrasting fish with mammals and other vertebrates.

Fish Anatomy



This part of the lab comes to you straight from the grocery store. You'll have the opportunity to examine a variety of fresh fish.

Fish Taxonomy

The taxonomy of Chordates can be confusing, because there are traditional, well-known groups (like fish) that don't reflect real evolutionary relationships. Most fish have traditionally been grouped in two classes within the phylum Chordata: **Osteichtyes**, or bony fish (which includes most kinds of fish) and the **Chondrichthyes**, or cartilaginous fish (which includes sharks and rays). However, the actual evolutionary relationships of fish are a bit more complex, as shown in the cladograms in Campbell, ch. 34.

This lab will focus on the bony fish, traditionally classified as Osteichthyes. Most of the bony fish belong to a group within the Osteichthyes called the Actinopterygii.

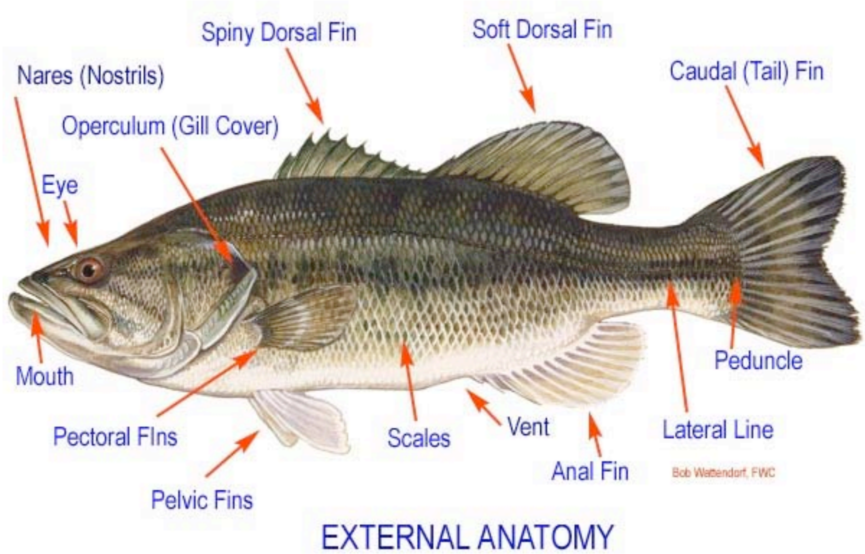
Fish Anatomy

In this handout, you'll see various diagrams with numerous anatomical features listed. Study them all, but the terms you're likely to see on a lab exam are those listed in bold type in the text of this handout. You won't be tested on everything in the diagrams.

External anatomy

Before you cut the fish open, see what you can learn from the outside. Note that different fish may have very different shapes, especially for their fins. Can you make any guesses about how your fish lives?

Look for the features shown in the diagram below.

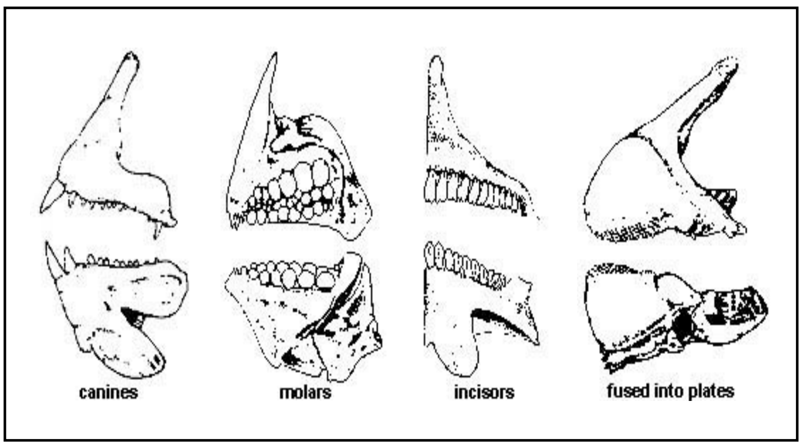


Fins: Note the caudal, dorsal, pelvic, pectoral, and anal fins. You'll see very different shapes of these fins in the various fish we have in lab.

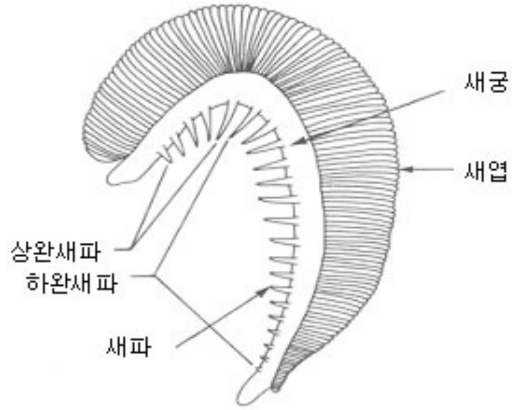
Lateral line: You may see a pigmented stripe marking the location of the **lateral line** sense organs. Can you see any evidence of the lateral line canals or organs?

Inside the mouth: Look inside the mouth. Note where the water would go as it passes over the gills, and note where the food would go when the fish eats. Take a look at the tongue. How is it different from your tongue? Note the **teeth.** Compare the teeth of the various fish in the room. Fish teeth come in a variety of syles, some of which are shown in the diagram on the next page.

In addition to the teeth in the jaws, fish often have **pharyngeal teeth** located back in the throat. The pharyngeal teeth are derived from pharyngeal arches, one of the key chordate characteristics. Why do you suppose they would have these "extra" teeth?



While you're looking in the mouth, look at the **gill arches** and the **operculum**. The gill arches are pharyngeal arches that support and protect the gills. The gill arches usually have **gill rakers** on the anterior (front) side. Gill rakers are small projections sticking out of the gill arch; they prevent the fish's food from escaping out through the gills. Fish that eat large prey have widely spaced gill rakers; fish that eat tiny zooplankton have closely spaced, filter-like rakers.



I have no idea what the captions say on the above figure (from http://gyeonggi.go.kr/fishs/fishs2.php). However, it's a picture of a gill arch with gills on the posterior side (the right in this picture) and gill rakers on the anterior side (left).

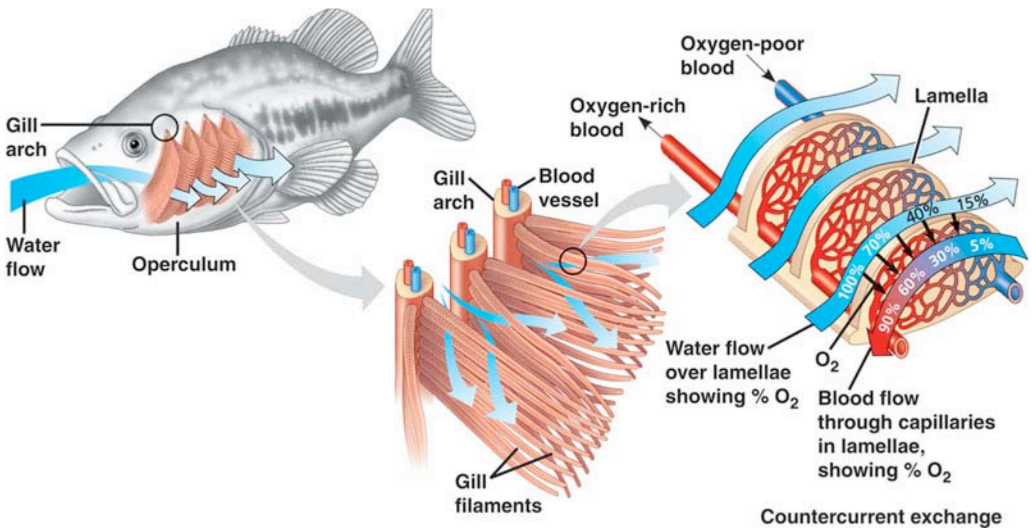
Note how opercular pumping might work in your fish. What would make the water enter the mouth? What would make it pass out across the gills?

Nostrils: where does the water go when it passes through the fish's nostrils?

Vent: Fish have a single opening, the **vent**, that serves as the anus and the urogenital opening. (Urogenital means urinary and genital – that is, the opening through which eggs or sperm pass during reproduction). Find the vent in your fish. The vent marks the posterior end of the body cavity; behind that, the fish is all tail.

Gills

Recall the structure of fish gills:

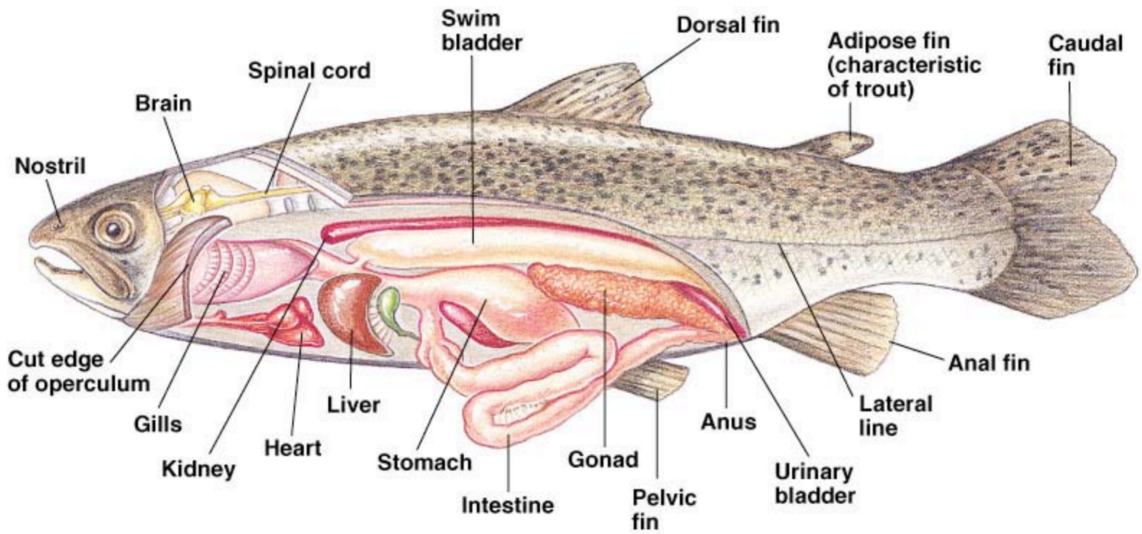


Cut away the operculum so you have a good look at the gills and the inside of the mouth. Each gill is supported by a bony gill arch, with the spiny gill rakers projecting forward. Note the **filaments** of the gills, each with many **lamellae**. You will be able to see this better under the dissecting microscope.

The fish's blood must flow through the gills to get oxygenated, so the gills are filled with blood vessels. The heart is located just behind the gills, but you won't be able to see it until you cut the body open. You'll come back to the heart in a little while.

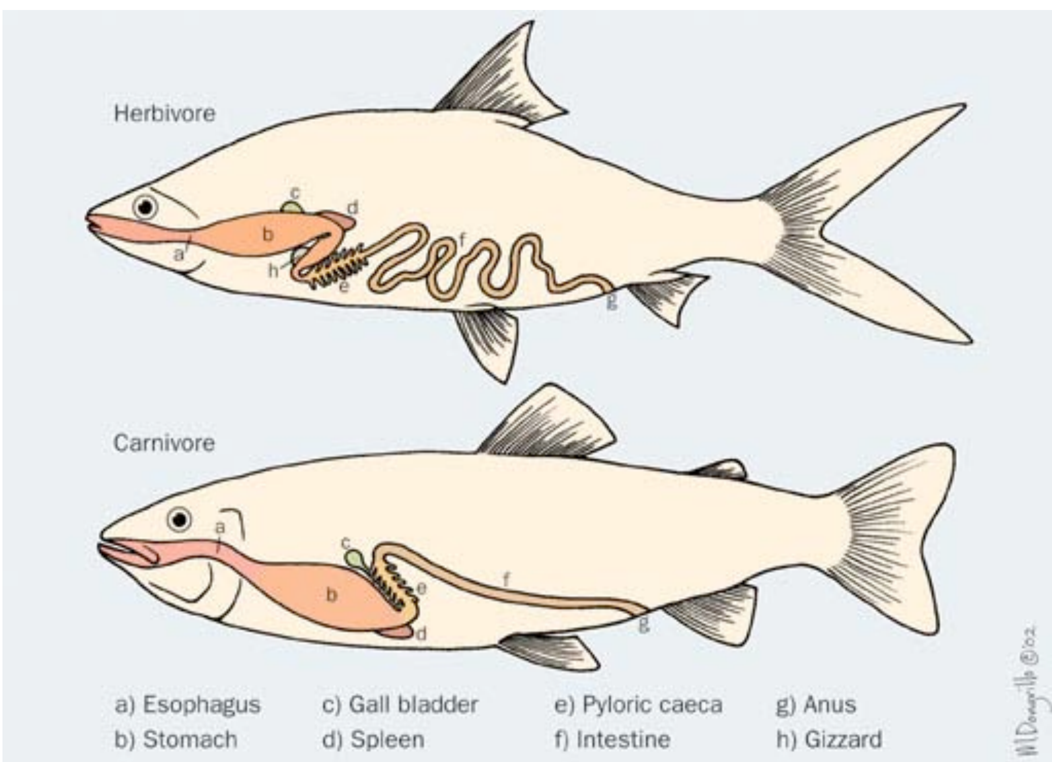
Inside the body cavity

Cut open the fish's body along the ventral (belly) side. You'll see all the internal organs sitting in the coelom. To get a better view, cut away one side of the body wall, removing the muscle, bone, and skin so you have an unobstructed view. Note the organs shown in the diagram below (diagram is from Campbell, ch. 34.)



Digestive tract. The digestive tract of fish is similar to that of mammals. Food passes from the mouth down the **esophagus** to the **stomach**. You may be able to see **pyloric ceca**, which function as accessory digestive glands (mammals don't have these). The **liver** is large; it secretes bile into the **gall bladder**, from which the bile passes into the intestine. The **intestine** is fairly long. You may find remnants of food in the stomach or the intestine.

Just like mammals, fish have digestive tracts that are adapted to the food they eat. Herbivorous fish generally have longer intestines to aid in digestion and nutrient absorption from their low calorie food. Some also have a **gizzard**, a muscular organ that helps to mash up the food for better digestion.



Swim bladder. The swim bladder is a large light-colored structure near the dorsal side of the body cavity. Bony fish can adjust their buoyancy by putting gas into the swim bladder. The most abundant gas in the swim bladder is oxygen, which comes from the blood. A specialized **gas gland** generates lactic acid, acidifying the blood in the gas gland and causing it to release its oxygen (remember the Bohr shift?). This gland is accompanied by a specialized countercurrent to maintain the incredibly strong gradient of oxygen partial pressure between the swim bladder and the blood. Some fish can have over 100 atmospheres of oxygen partial pressure in the swim bladder, but their blood can never contain more O_2 pressure than the surrounding water, which never contains more O_2 pressure than the air (0.2 atm).

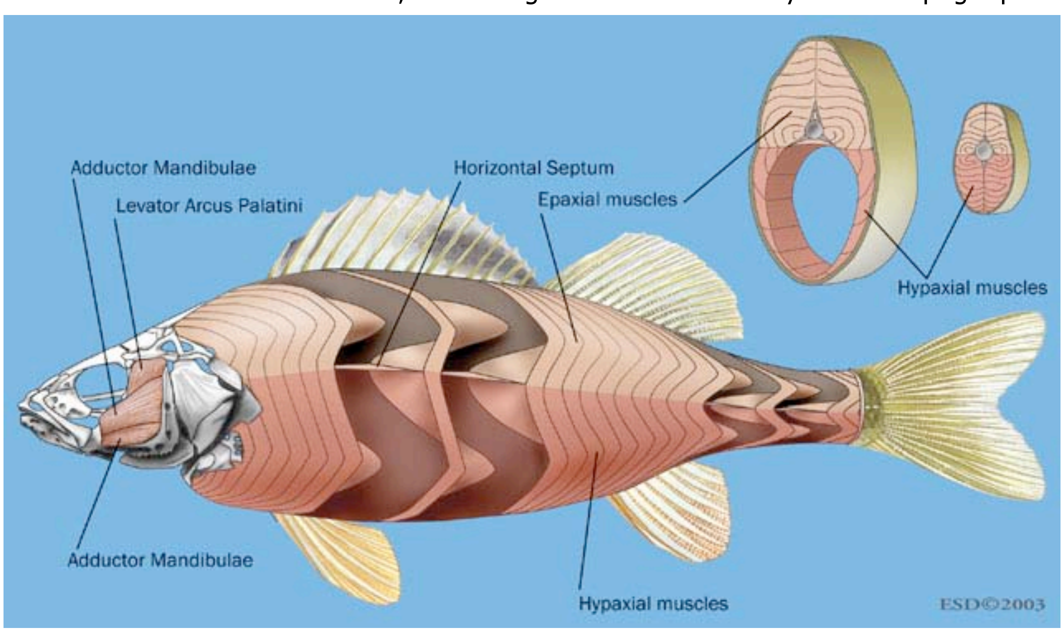
Kidney & urinary bladder. Does your fish live in salt water or in fresh water? Either way it has a kidney, but the function of the kidney is quite different in these two environments. The kidney is long and thin and dark; it is located along the very top of the body cavity. Urine produced by the kidney enters the urinary bladder, which exits into the same area as the anus and the gonad.

Gonad. Most fish are either male or female, though some change sexes. You should be able to see either an **ovary**, which may be filled with large orange eggs, or a **testis**, filled with white sperm.

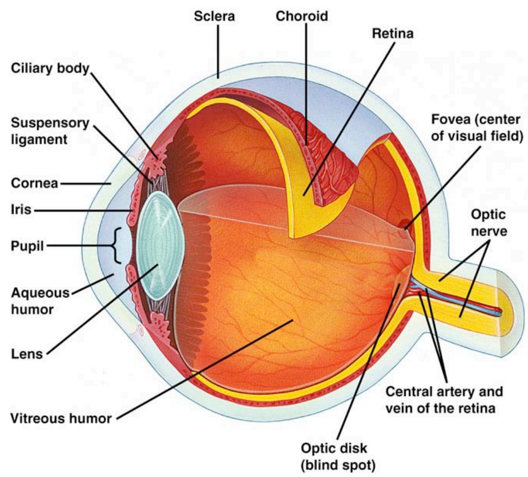
Circulatory system. Remember that fish pump their blood once per circuit. The **heart** is located close to the gills, and blood passes through the gills and then through the systemic circulation before making it back to the heart. You may have to do a little extra dissection to find the heart; it's typically just behind and beneath the gills. Note the direct blood flow from heart to gills.

Other anatomical features

Muscle. Fish have a lot of muscle. If you peel away the skin, you can see the sections of muscle that are familiar to anyone who eats fish. The muscle of fish provides a very clear example of the segmented mesoderm that is characteristic of chordates. Also note the **rays of the fins**. Most fish can pull their fins flat to the body or extend them. The fins are extended by rays that penetrate down into the fish's muscle; the flexing muscle levers the rays into an upright position.

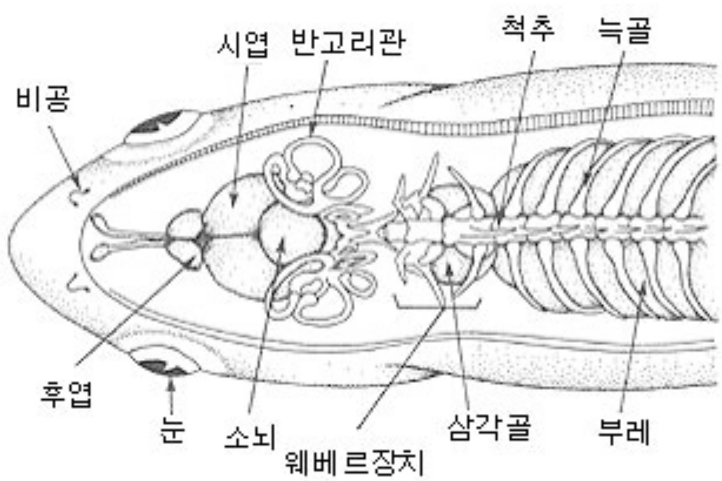


Eyes. If you're good at dissecting small things, you may be able to sort out the anatomy of the eye. It's a bit squishy, but you may be able to find some of the features shown below:



Note that in fish eyes there is usually a **tapetum** behind the retina; this silvery reflective layer bounces light back to the photoreceptor cells in the retina, allowing the fish to see better in low light. Many mammals also have this feature, but humans don't.

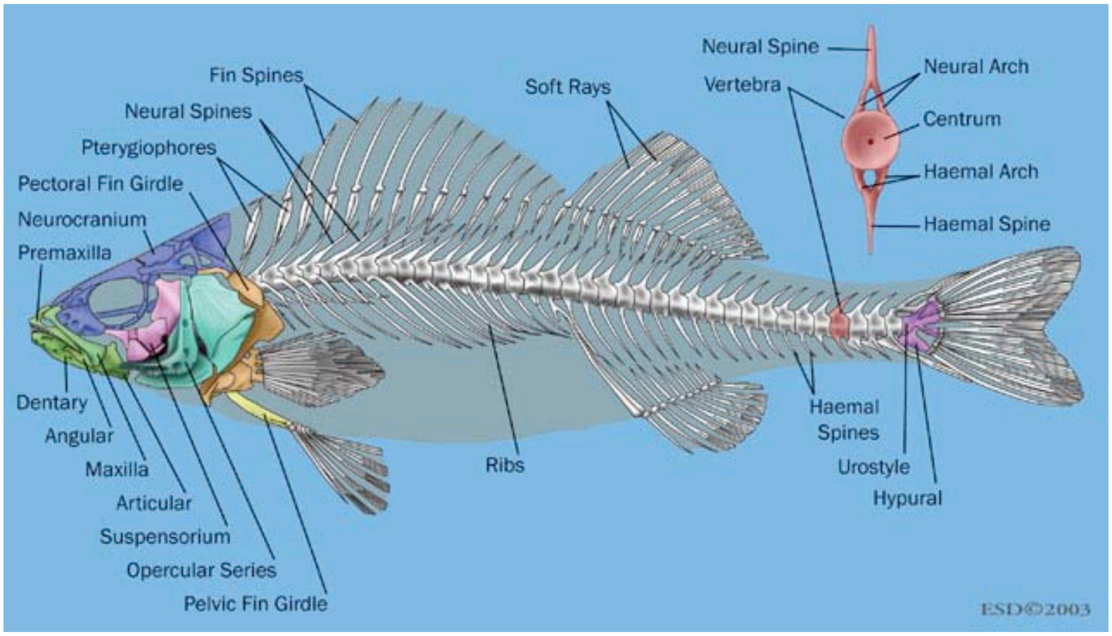
Brain. It takes a little work with scissors, but you can cut open the brain case and find the brain inside. You'll probably have a hard time locating the different regions of the brain, but here's a diagram:



잉어 과 어류의 뇌 (brain)와 웨베르장치 (weberian apparatus)

Note that there are large semicircular canals (balance organs) associated with the brain.

Skeleton. Fish live in the water, and they don't have to support all their weight with their skeletons. For this reason, fish skeletons are generally much weaker than mammalian skeletons. That's why you can cut the skull open with scissors. Compare your fish to the mounted fish skeletons in lab. We'll look at skeletons in more detail in a later lab.



Neural Spine
Neural Arch
Fin Spines
Soft Rays
Vertebra
Neural Spines
Centrum
Pterygiophores
Haemal Arch
Pectoral Fin Girdle
Neurocranium
Haemal Spine
Premaxilla
Dentary
Angular
Maxilla
Articular
Suspensorium
Opercular Series
Pelvic Fin Girdle
Ribs
Haemal
Spines
Urostyle
Hypural
ESD©2003

Terms and structures to remember:

There are two parts to this lab: chordates in general, and the anatomy of fish.

Chordates

- Appendicular skeleton
- Atrium
- Axial skeleton
- Cephalochordate
- Chordata
- Cranium
- Deuterostome
- Dorsal hollow nerve cord
- Gastrulation
- Myotomes (muscle segments)
- Neurulation
- Notochord
- Pharynx; pharyngeal slits; pharyngeal basket
- Tail
- Urochordates
- Vertebral column
- Vertebrate

Fish Anatomy

You should be able to identify the following structures in any of the fish that are in today's lab (remember, other groups may have different species of fish – you should look at them all).

- Fins: pectoral, pelvic, dorsal, anal, caudal
- Gills, gill arches, gill rakers
- Gonad (ovary or testis)
- Heart
- Intestine
- Kidney
- Lateral line
- Liver & gall bladder
- Operculum
- Pyloric ceca
- Stomach
- Swim bladder
- Teeth and pharyngeal teeth
- Vent