Lab 9 - Vertebrate Organ Systems

Objectives:

- **Understand the taxonomic relationships and major features of the chordates and the major classes of vertebrates**
- **Identify structures and their functions associated with major systems - nervous/sensory, respiratory, circulatory, digestive and excretory - in different vertebrates**
- **Learn the taxonomic relationships between groups, to understand when similarities between structures are based on history (homology) or convergence**

Introduction:

As you will recall from the Introduction to Animal Diversity handout, organisms need to carry out many processes to survive and reproduce. During the next two weeks, you will examine the internal organs of vertebrates as a way of understanding their anatomy and physiology. As before, please approach your studies of vertebrate anatomy and physiology as suggested on pp. 1-2 of the Animal Diversity handout. Once again, you should understand that similarities or differences in vertebrate systems are often a reflection of the environment in which an animal lives and the type of food that it eats. Finally, think about how the anatomical and physiological solutions of vertebrates compare with those that you observed earlier in invertebrates.

Textbook Reference Pages: pp. 717-718 and 722 -741

Phylum Chordata

The Phylum Chordata contains the group most familiar to you – the vertebrates. The members of this phylum are distinguished by:

1) They are **triploblastic**, possessing an ectoderm and endoderm, and a middle tissue layer, the **mesoderm**. They are **coelomate**, possessing a true body cavity lined on all sides by mesoderm-derived tissues.

2) Chordates are **bilaterally symmetrical**.

3) They have a **notochord**, a flexible supportive rod that runs longitudinally through the dorsum.

4) Chordates have a **dorsal hollow nerve cord**, which lies dorsal to the notochord.

5) They possess **pharyngeal gill slits,** which lie between the oral cavity and the esophagus.

6) Chordates also have a **postanal tail**.

These features may not be present throughout the life cycle of chordates, but may only appear during the embryological stages of development.

The phylum is divided into three subphyla:

Subphylum Urochordata, the tunicates.

Subphylum Cephalochordata, the lancelets.

Subphylum Vertebrata, the vertebrates, and the only group of chordates that we will look at in lab.

Specimens of Vertebrates

The focus of these labs is for students to become familiar with the organ systems of vertebrates (as compared to invertebrate systems), and along the way you should become more familiar with the taxonomy and major features of different groups of vertebrates. There are several classes in the Subphylum Vertebrata, and we will look at six in lab:

Class Chondrichthyes – sharks, skates and rays: the cartilaginous fishes (Dogfish)

Class Actinopterygii – bony fishes (Perch)

Class Amphibia – amphibians: frogs, salamanders, newts, etc. (Frog, Mudpuppy)

Class Reptilia – reptiles: snakes, lizards, crocodilians, etc. (Snake)

Class Aves – birds (Pigeon)

Class Mammalia – mammals (Pig)

Students will have two weeks to examine these materials. Careful dissections of the following specimens should be performed by <u>all</u> students, with suggested group size indicated in parentheses.

1) Fetal pig (2)
2) Sheep heart (2)
3) Sheep eye (2)
4) Dogfish shark (7-8)

Please take your time with these dissections. Do NOT cut out and remove organs from the pig or sharks, as viewing structures in their relative positions within the animal is critical for understanding the function of each organ and organ system. Also, we have fewer sharks, so please be especially careful with these specimens. Please do not try to dissect out the brain in the pig or shark, as we do not have the proper tools for opening up the skull cavity. At the end of each lab period, store the specimens in a tightly-sealed, labeled (with your names and lab day) Ziploc bag, and discard fat tissue, etc. in the yellow trash can in the front of the lab.

An overview of how to approach your dissection of the fetal pig is on the next two pages. Please follow these guidelines to get yourself oriented. Then, we suggest that you focus in sequence on specific organ systems, to understand how individual organs of that system work together to carry out an overall function for the organism. Thus, we have organized the remainder of this lab according to the particular physiological challenges that each organ system addresses. Once you understand how each of the organ systems work in the pig, you should then compare and contrast the mammalian body plan with that of the other vertebrate specimens in lab. In addition to performing a group shark dissection, a pre-dissected frog will be available for viewing on the front bench, as well as resin mounts of a dissected bird and snake. There will also be various microscope specimens, models and other resin mounts in the front of the lab. Finally, in lab, there will be several different dissection booklets and dissection guides in plastic sleeves to assist in your understanding.

<u>ALL</u> OF THESE MATERIALS ARE TO REMAIN IN LAB FOR <u>ALL</u> STUDENTS TO USE.

Note: sharks will be available for dissection in the *second* week of this lab, and you should study *all* of their organs systems at that time.

Fetal Pig Dissection

Please review the **"Tips For Doing Good Dissections"** sheet on p.4 of the Introduction to Animal Diversity handout. During lab, you will be responsible for maintaining detailed laboratory notes of your observations. You are expected to be able to identify the structures on the following *Fetal Pig Dissection Check List* (p. 4) and to know the basic function of each structure. A detailed Power Point show of a fetal pig dissection is posted on the course Blackboard site, as well as several on-line dissection sites, for your out-of-lab perusal.

Place your pig on its back in the dissection pan and press down on its chest and abdomen to flatten it out. Then, keep the ventral surface open by tying the fore and hind limbs up with a piece of twine (your lab instructor will demonstrate how to do this). First, examine the external anatomy of your pig and use Figure 2 below to determine if you have a male or female pig. Next, follow the numbering sequence in Figure 3 to cut through the skin and body wall of the pig. As you examine the internal organs (Figure 4), you want to note how the organization of an organ and its respective organ system is related to the specific body function that the organ carries out. In addition, this is a good time to reflect upon the role of animals in teaching and research. As such, **make sure that you treat your animal with the proper respect.**

ANATOMICAL TERMS AND PLANES:

- Anterior - Posterior (head to rear)
- Ventral - Dorsal (belly to back)
- Rostral - Caudal (nose to tail)
- Medial - Lateral (midline to side)
- Superior - Inferior (above to below)
- Proximal – Distal (closer to/farther away from a point of reference)

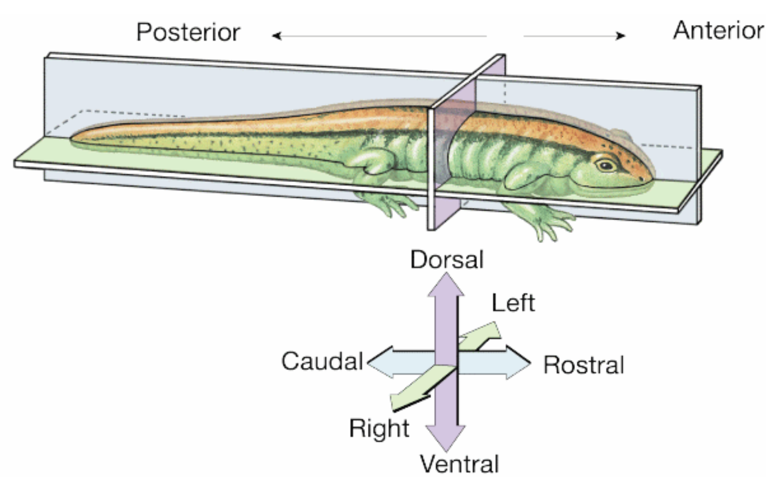


Figure 1. Anatomical terms and planes as applied to a tetrapod vertebrate

FETAL PIG DISSECTION CHECK LIST

_____ lungs and pleura

_____ trachea and bronchi

_____ heart and pericardium

_____ nose and mouth

_____ rib cage and diaphragm

_____ liver and gall bladder

_____ umbilical arteries (2) & vein

_____ umbilical cord

_____ stomach

_____ small and large intestines

_____ kidneys and ureters

_____ renal arteries/veins

_____ bladder and urethra

_____ rectum/anus

_____ male vs. female urogenital system

_____ hard and soft palates

_____ pharynx

_____ teeth and tongue

_____ nasal and oral cavities

_____ larynx

_____ abdominal cavity

_____ esophagus

_____ thoracic cavity

_____ pancreas

_____ caecum

_____ aorta

_____ pelvic cavity

_____ pulmonary trunk

_____ aortic arch

_____ ductus arteriosus

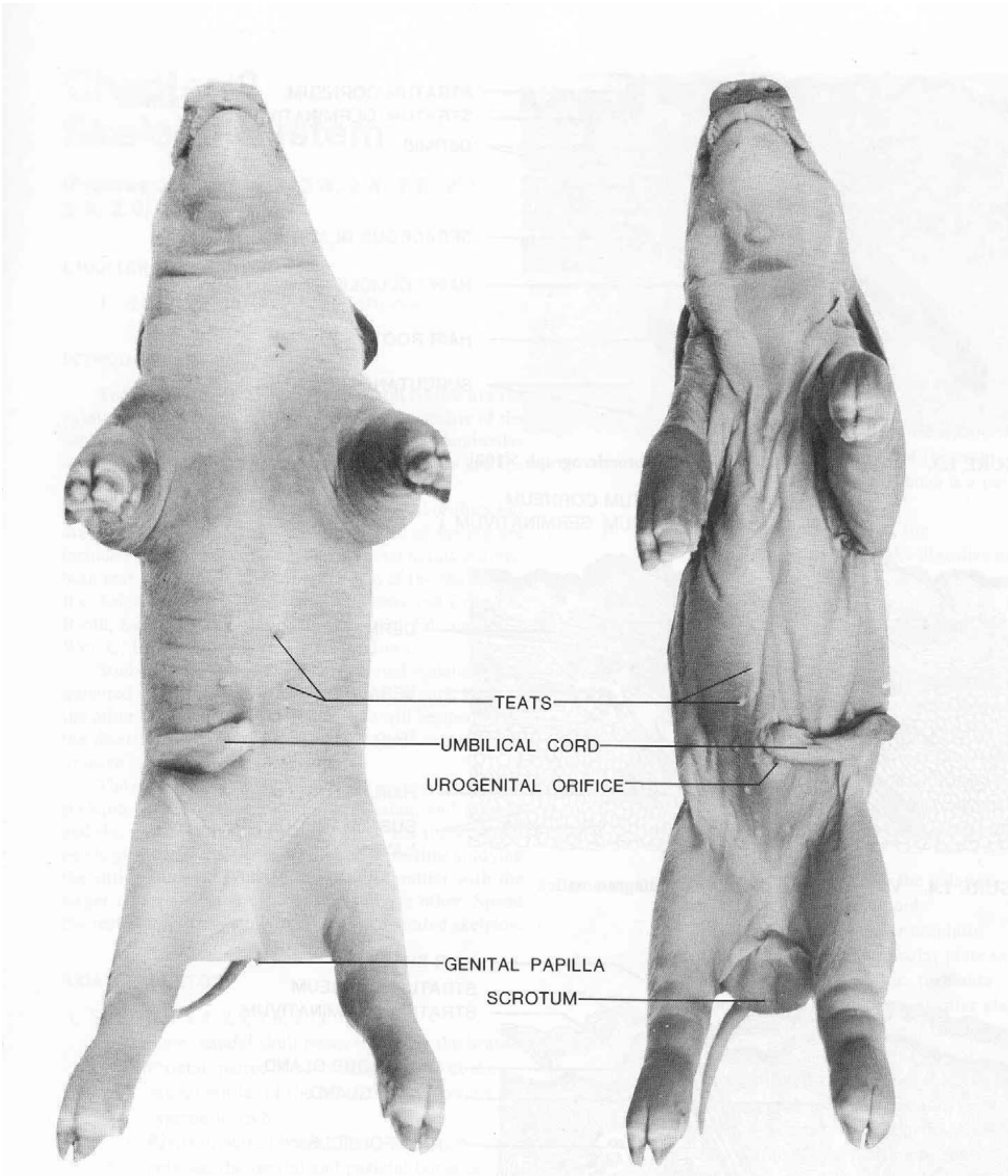


Figure 2. Ventral view of female (left) and male (right).

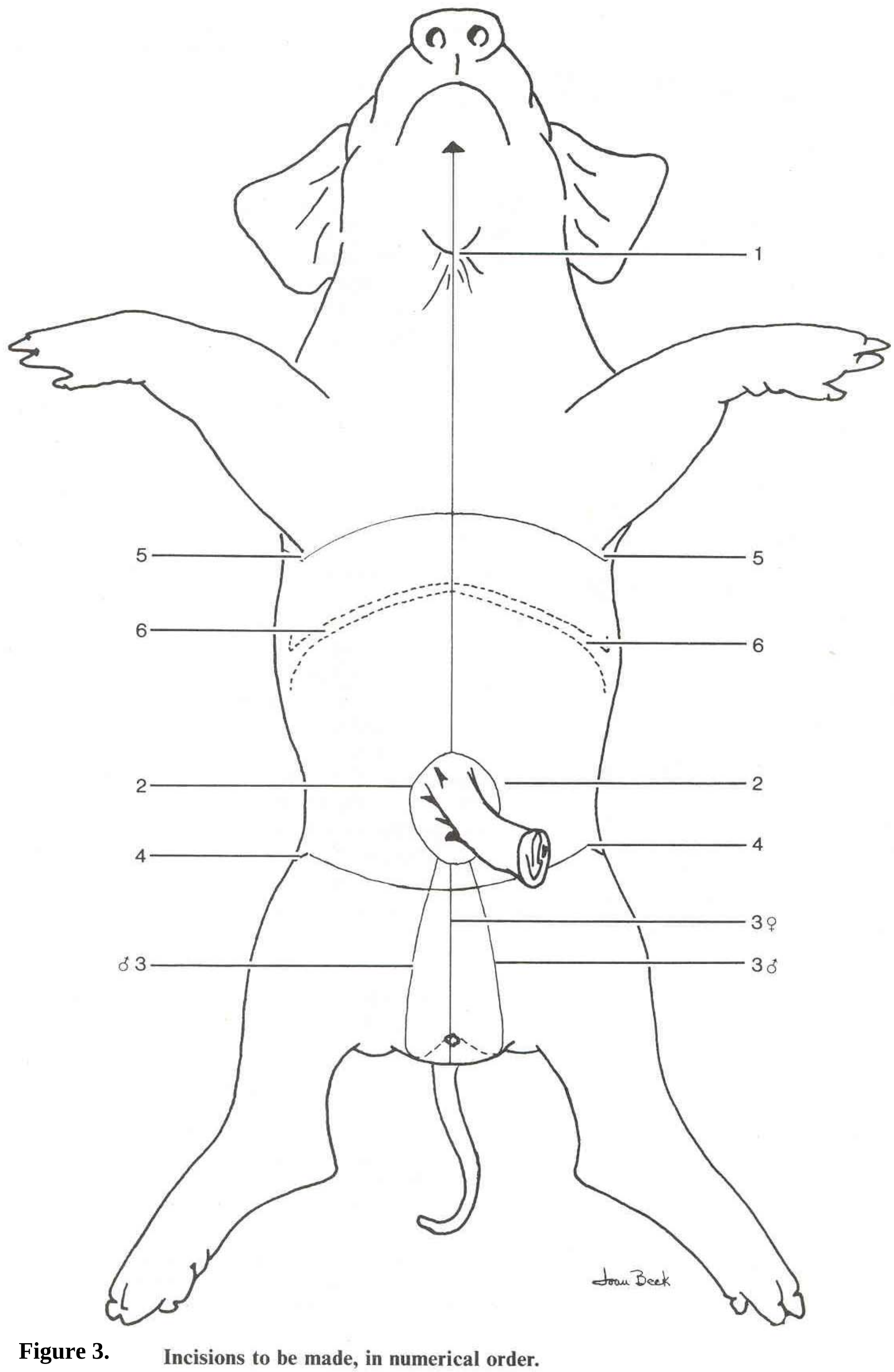


Figure 3. Incisions to be made, in numerical order.

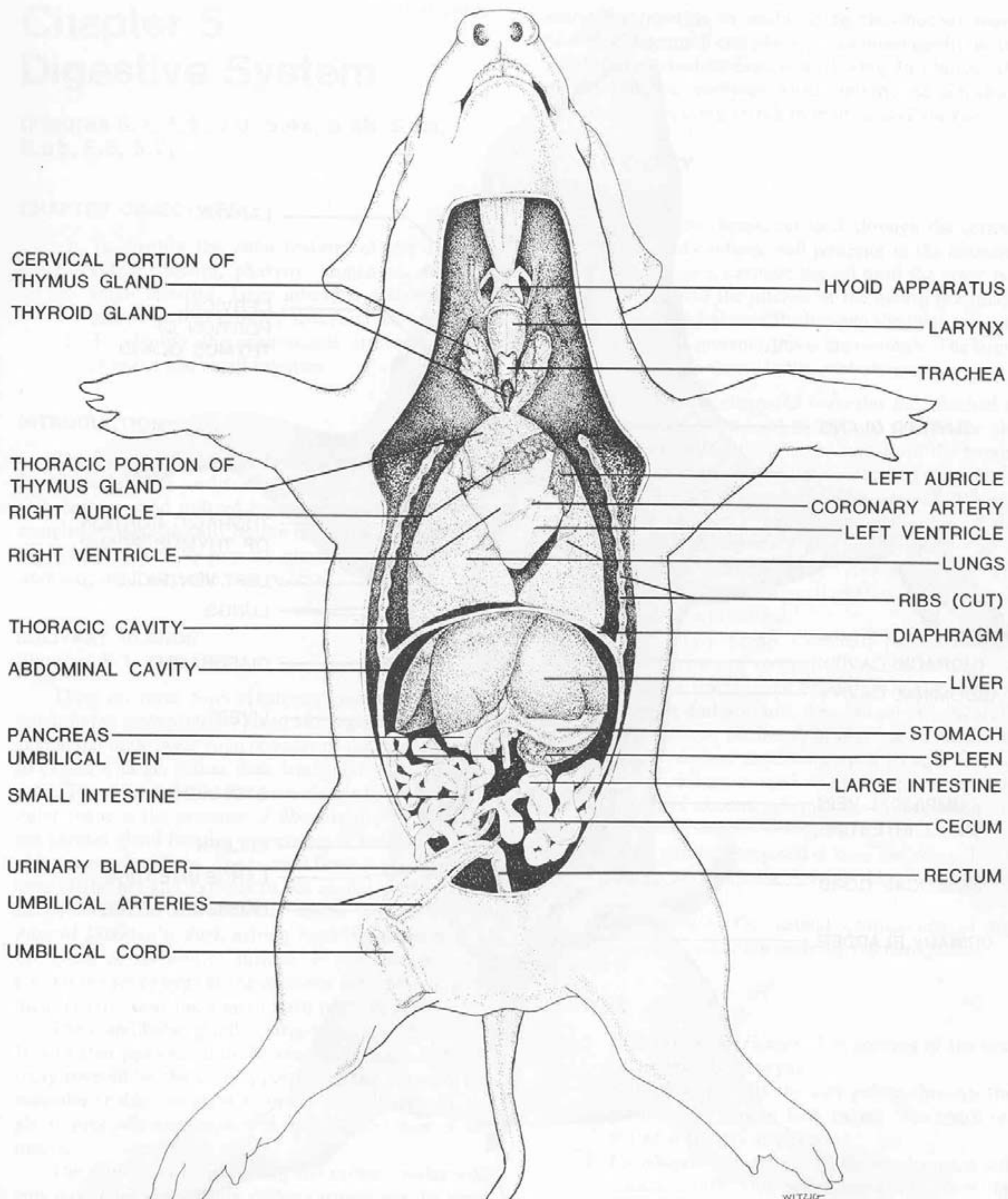


Figure 4. **General internal anatomy, ventral view.**

Figures 2-4 from Odlaug, 1992, *Laboratory Anatomy of the Fetal Pig*, 9th ed.

DIGESTIVE SYSTEM (FOOD PROCESSING)

Textbook Reference Pages: pp. 1075-1085

As discussed on p. 12 of the Worm lab handout, most of you are probably familiar with how you digest your food. First, you break apart the food with your **teeth** and enzymes (amylase) found in your **saliva** begin the chemical digestion of carbohydrates**.** Then you swallow the smaller bits, and acid and enzymes (pepsin, which digests proteins) in your **stomach** break it down further. Digestion of large molecules into small monomers (e.g., amino acids, monosaccharides, fatty acids and nucleotides) is completed in the **small intestine.** The **pancreas** releases bicarbonate ions (to neutralize the stomach acid) and a number of different enzymes into the small intestine to assist in chemical digestion. The **gall bladder** stores bile that is synthesized by the **liver**, and a series of ducts deliver bile to the small intestine from these organs. **Bile** emulsifies fats, which increases the surface area of fat globules for chemical digestion by enzymes (e.g., lipases).

Although substances like alcohol and caffeine can be absorbed across the stomach lining (hence the buzz when consumed on an empty stomach), the site of most absorption of nutrients is the **small intestine**. The surface of the small intestine is lined with **villi**, finger-like projections of the luminal surface of the intestine that greatly increase the surface area for digestion. The small intestine has three specialized regions: 1) the **duodenum**, where most digestion occurs, 2) the **jejunum**, and 3) the **ileum**, where (with the jejunum) 90% of the absorption of nutrients occurs. From the small intestine, material passes into the **colon** (large intestine) where water and ions are absorbed into the blood. Undigested wastes are eliminated through the **rectum** and **anus**. Before returning to the heart, all blood leaving the stomach and intestines first passes through the **liver**, which takes up and processes various nutrients.

Use the fetal pig to review the structure and function of the mammalian digestion system (Figure 5). Then compare and contrast the mammalian digestive system with that of the shark, frog, snake and bird, by examining those specimens (see also Figures 6 & 7). Think about what kinds of materials each type of animal consumes, and ask yourself questions such as the following. What does the organism use to capture its food? Does the organism have teeth (or tooth-like structures)? Does it need them (maybe it only consumes soft food or swallows its prey whole)? How convoluted is the small intestine? What are the implications of increasing the length and folding of the small intestine?

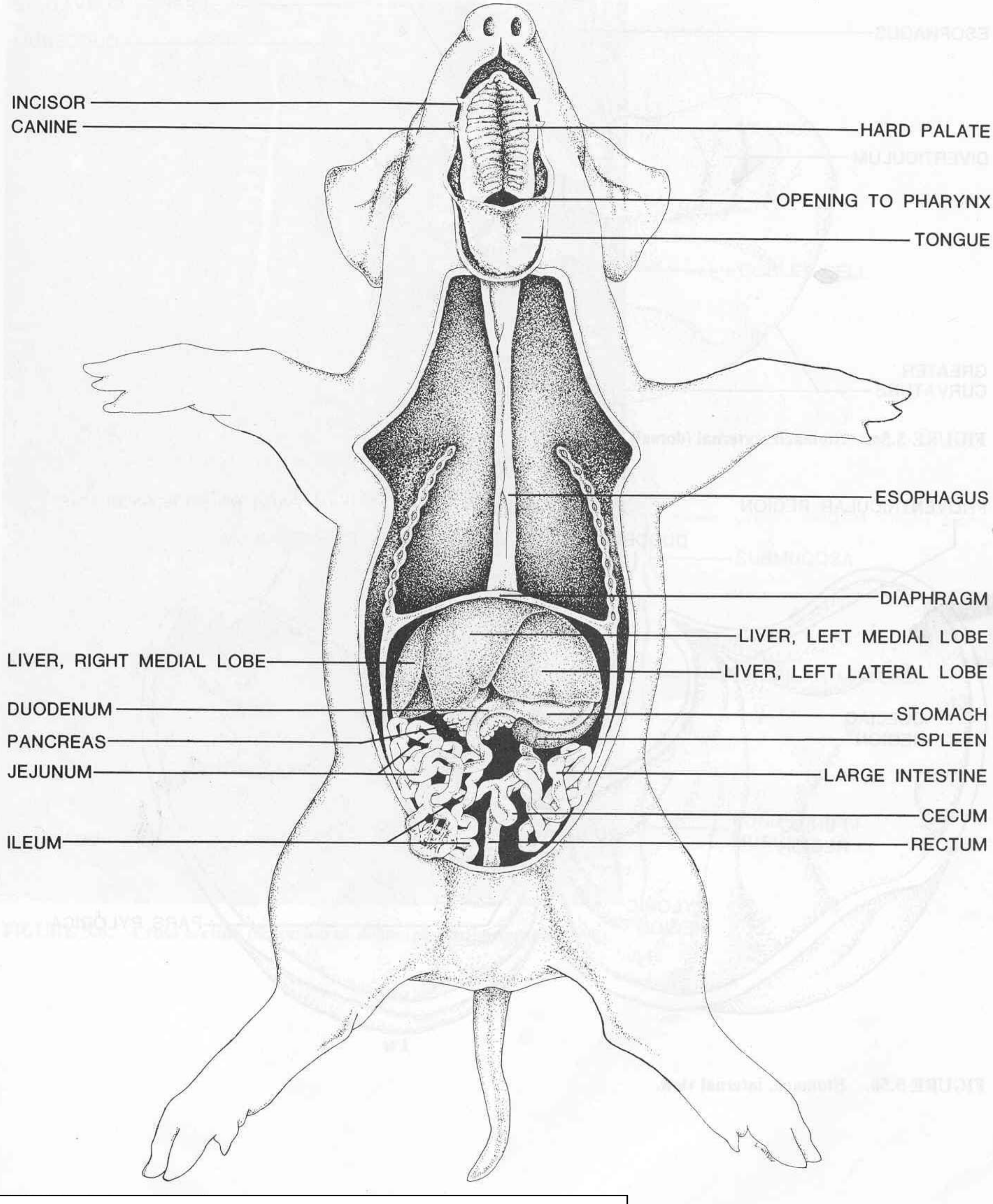


Figure 5: Digestive system of the fetal pig, ventral view (from Odlaug, 1992, *Laboratory Anatomy of the Fetal Pig*, 9th ed.).

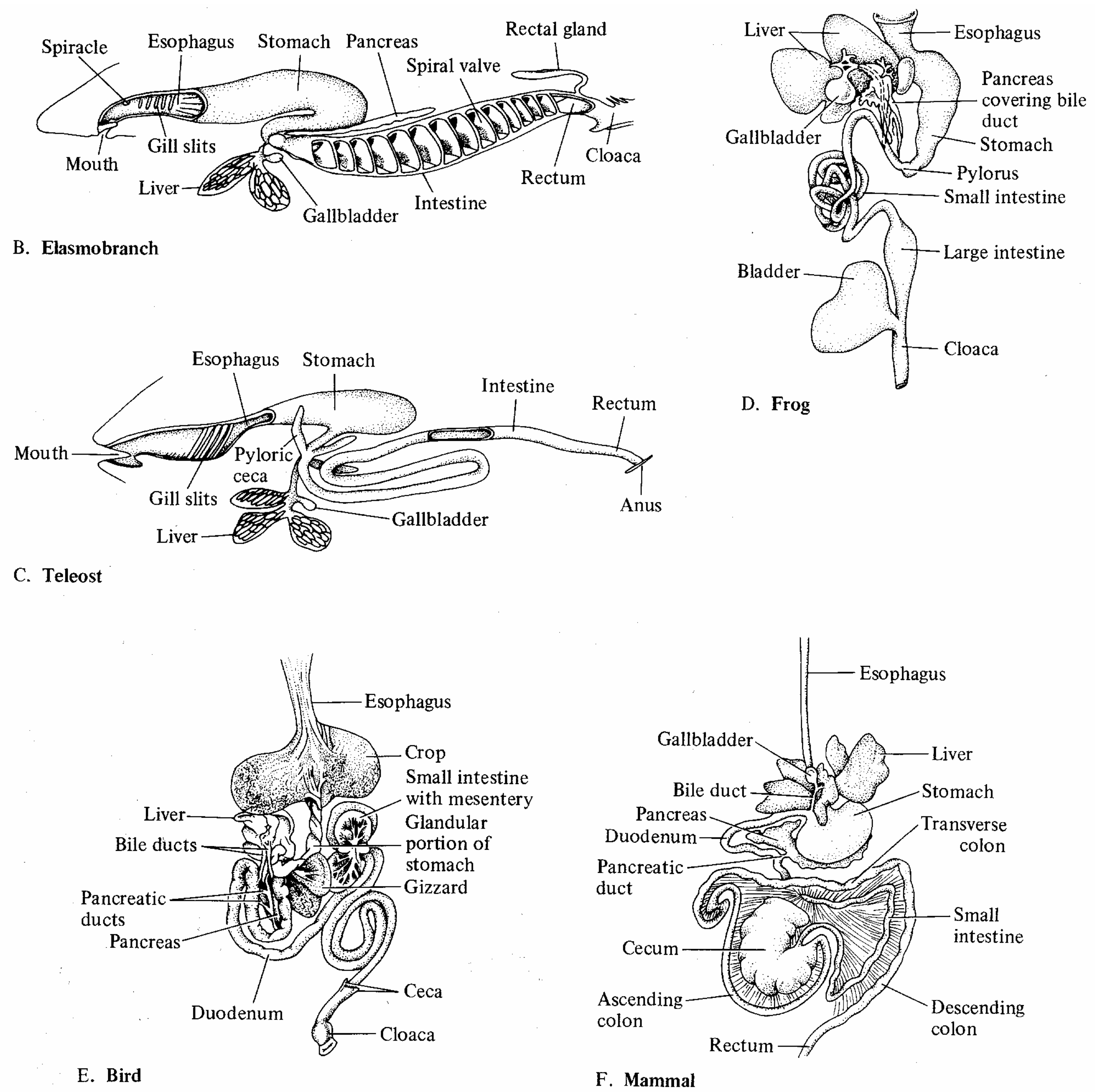


Figure 6: Representative vertebrate digestive systems, showing progressive anatomical specialization for digestion (stomach and accessory digestive glands such as pancreas and liver) and absorption (surface area of small intestine). Shown are B. Elasmobranch (shark), *Squalus*, C. Teleost fish, *Perca*, D. Frog, *Rana*, E. Bird, *Columba*, F. Mammal, *Cavia*. (from Withers, 1992, Comparative Animal Physiology).

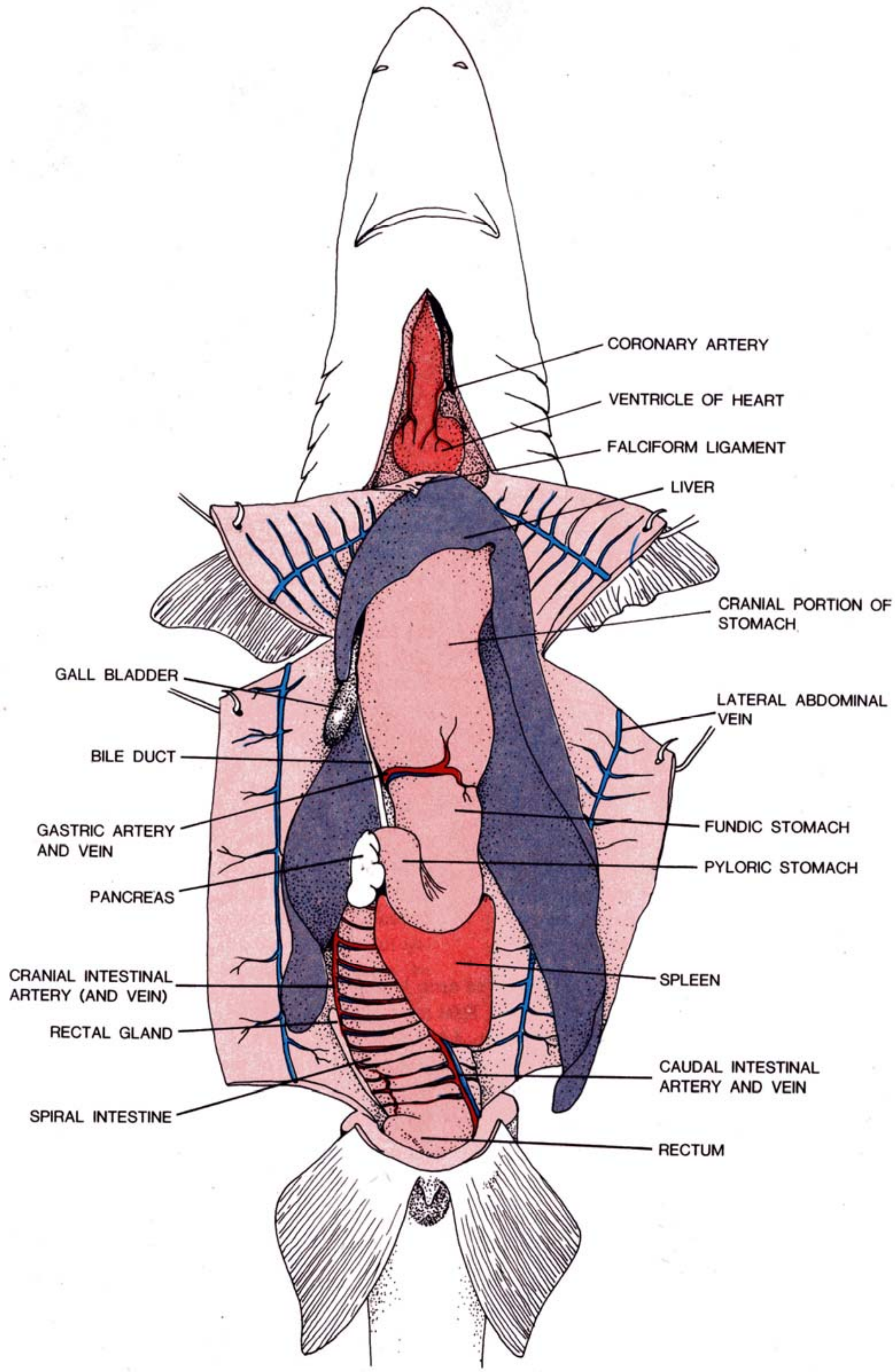


Figure 7. **Ventral view of the shark viscera and heart.**

(from Ashley & Chiasson, 1988, *Laboratory Anatomy of the Shark*, 5th ed.

RESPIRATORY SYSTEM (EXCHANGE OF GASES)

Textbook Reference Pages: pp. 1029-1035

As we saw with invertebrate gas exchange, whether a vertebrate is aquatic or terrestrial makes a profound difference on the type of organ that it uses for gas exchange. Fish rely almost exclusively on external **gills**, whereas terrestrial vertebrates have enclosed their respiratory surfaces inside the body as paired **lungs**. In this situation, air is conditioned (e.g., warmed, humidified and filtered) as it passes through the large airways into the lungs and accessory organs, such as the **ribs** and **diaphragm**, help move air into and out of the lungs. It is also important to remember that water holds ~20X less oxygen than air, and respiratory structures that evolved in water don't work in air, because air is not as supportive as water and the structures collapse in air.

You will recall that in all cases, there are three basic factors that evolution has acted upon to meet the oxygen demands of these larger animals: 1) increasing the surface area of the exchange surface, 2) decreasing the distance of diffusion between the respiratory medium and the blood at the exchange surface, and 3) maximizing the concentration gradients of O_2 and CO_2 between the respiratory medium and the blood at the exchange surface (such as countercurrent exchange systems). Notice here that we mentioned the exchange between the respiratory medium and the blood - although we are presenting them as separate systems, it is critical that you understand the relationship between the respiratory and circulatory systems.

Vertebrate Respiratory Systems:

Fish -- As you look at the specimen of the perch and view its gills under the microscope (both the dissecting scope for a mid-range look and the compound scope for a closer look), think about the process of moving water over the gills and how exchange of gases happens across the delicate gill filaments (Figure 8a,b). How does a countercurrent exchange system work? How is it different from co-current, crosscurrent (birds), or pooled (mammals) exchange systems?

Amphibians -- How are the gills of the mudpuppy (*Necturus*) similar and different from fish gills? Are they as branched (do they have as much surface area)? How about the diffusion distance - is the skin over their gills thicker than the skin over fish gills? Do you think these gills work by countercurrent exchange? Do they have to? Many amphibians also exchange gases across their cutaneous surface (skin), and the mudpuppy is a good example of this. Fish have some gas exchange across the skin's surface, but not nearly as much as amphibians (usually less than 10%). Bullfrogs (*Rana*) can exchange up to 60% of their oxygen and carbon dioxide across the skin!

Reptile -- As you look at the snake lung(s), be sure to compare them to the drawing of the amphibian lung in Figure 9. Reptiles have dry, scaly skin and thus cannot exchange gases there - one thing they lost in the transition from the water to land. As a result they had a dramatic increase in lung surface area with increased compartmentalization. What other problems did reptiles have to contend with when they left the water?

Mammals -- The difference in the amount of surface area (by body mass) of a lizard lung and a mammal's lung is dramatic. This makes sense, given the jump from an ectotherm to an endotherm, and the increased metabolic demands of mammals coincide with an increase in the need for oxygen. Look at the branched inner surface of the sheep lungs on display (Figure 10). In addition, examine the microscope slide of the alveoli, the functional unit of the lungs where gas exchange actually takes place. It has been estimated that each lung of an adult human contains ~450 x 10^6 alveoli!

Birds -- The metabolic costs of flight are enormous, so in conjunction with the evolution of flight in birds came a real innovation in the way gases are exchanged. Mammals have a pooled system of gas exchange, which isn't particularly efficient. Birds do it differently - they have managed a one-way flow of air through the lungs to maximize the concentration gradient of gases between the air and the lung surface. (Use Figures 48.7 & 48.8 in your text when trying to figure this out). Does the lung tissue itself look different between the sheep and the bird? Can you trace a breath of air through the lungs of a bird? (Use the diagram to the side of the dissection - it is hard to do this in a real bird because you cannot see all of the air sacs.

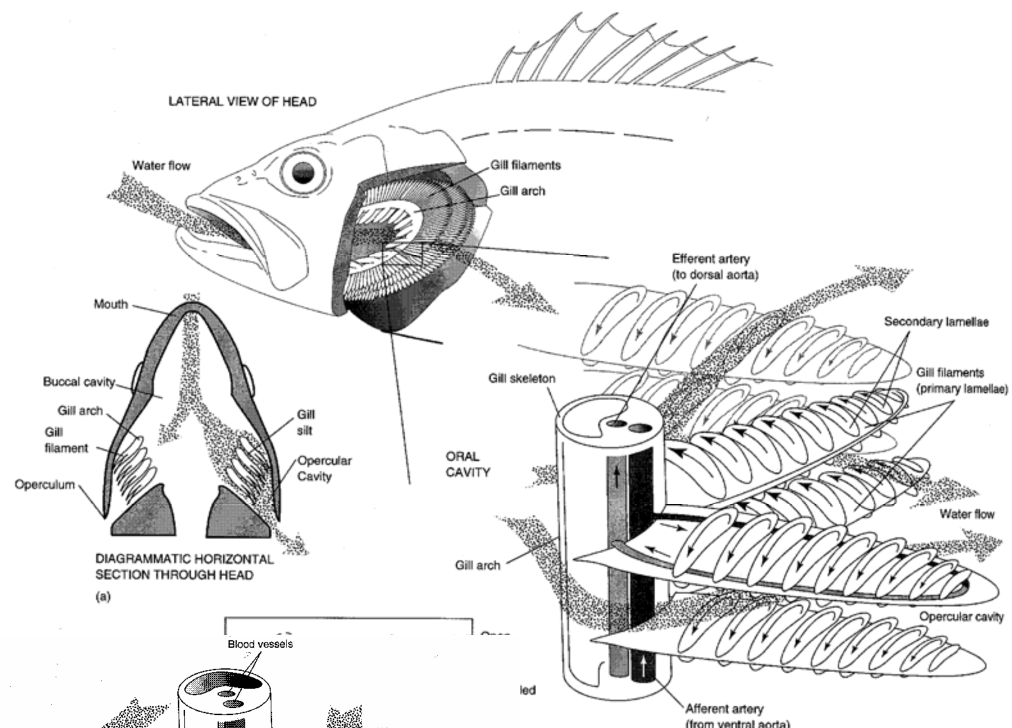


Figure 8a: Anatomy and functional morphology of teleost gills: (a) position of gills and general flow of water; (b) water flow (shaded arrows) and blood flow (solid arrows) patterns through the gills (from Pough et. al., 1992, Vertebrate Life, 4th ed.)

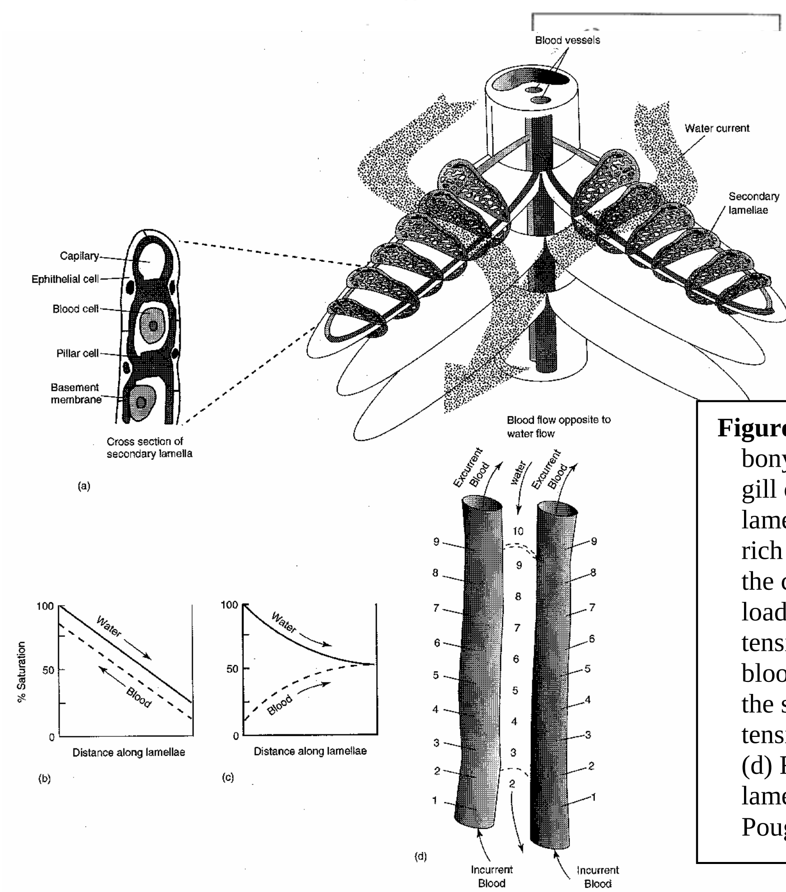


Figure 8b: Countercurrent exchange in the gills of bony fish. (a) The direction of water flow across the gill opposes the flow of blood through the secondary lamellae. Blood cells are separated from oxygen rich water by the thin walls of the gill epithelium and the capillary wall. (b) This results in a higher oxygen loading tension in the blood and a lower oxygen tension in the water leaving the gills. (c) If water and blood flowed in the same direction over and within the secondary lamellae, an overall lower oxygen tension would occur in the blood leaving the gills. (d) Relative oxygen content of blood in secondary lamellae and the water passing over them (from Pough et. al., 1992, Vertebrate Life, 4th ed.)

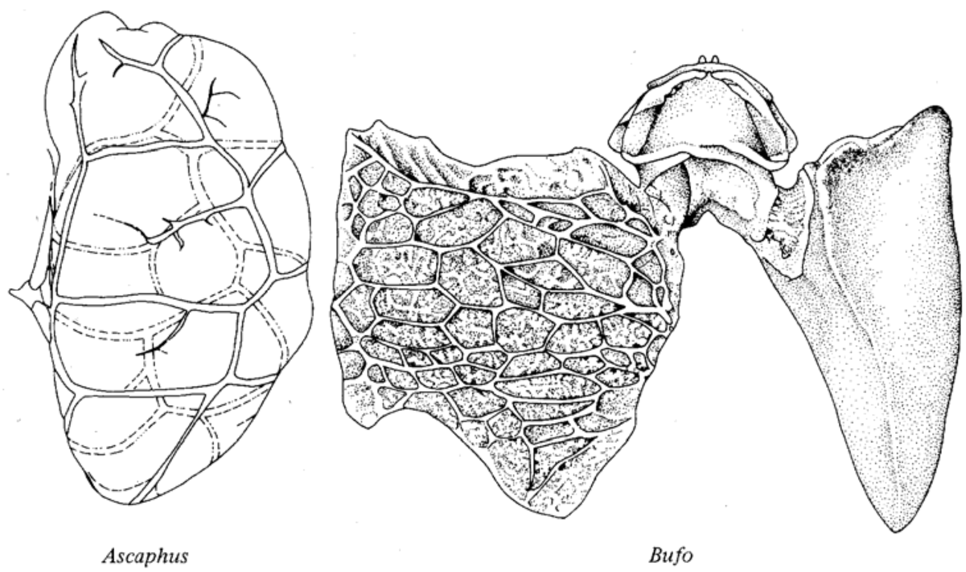


Figure 9: Simple sac lung of the amphibian *Ascaphus* and the moderately compartmentalized lung of *Bufo marinus*, the marine toad (from Noble, 1931).

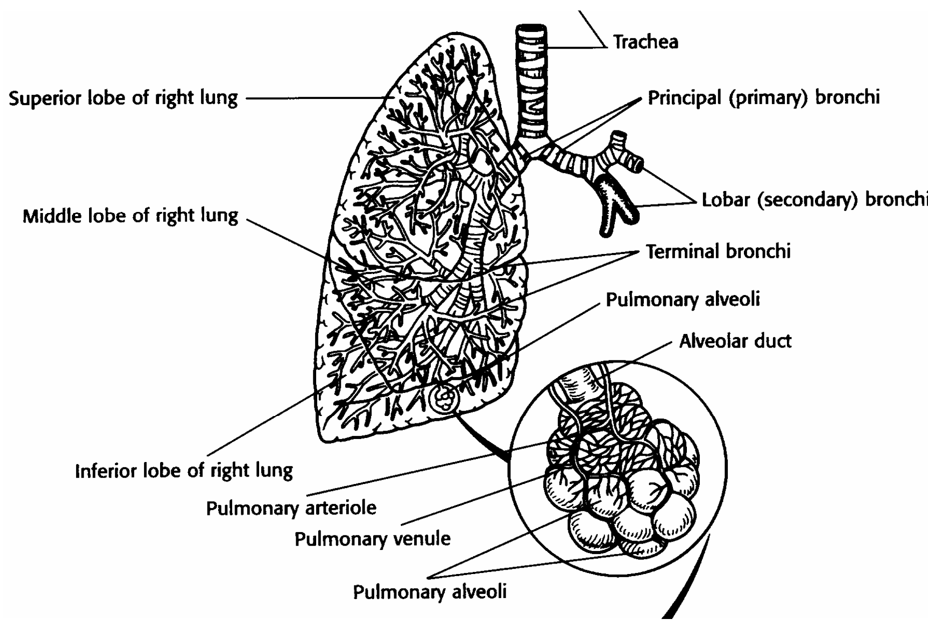


Figure 10a: Schematic of the lungs of a mammal, with an enlargement of the alveolar duct and alveoli (from Hopkins & Smith, 1997, Introduction to Zoology).

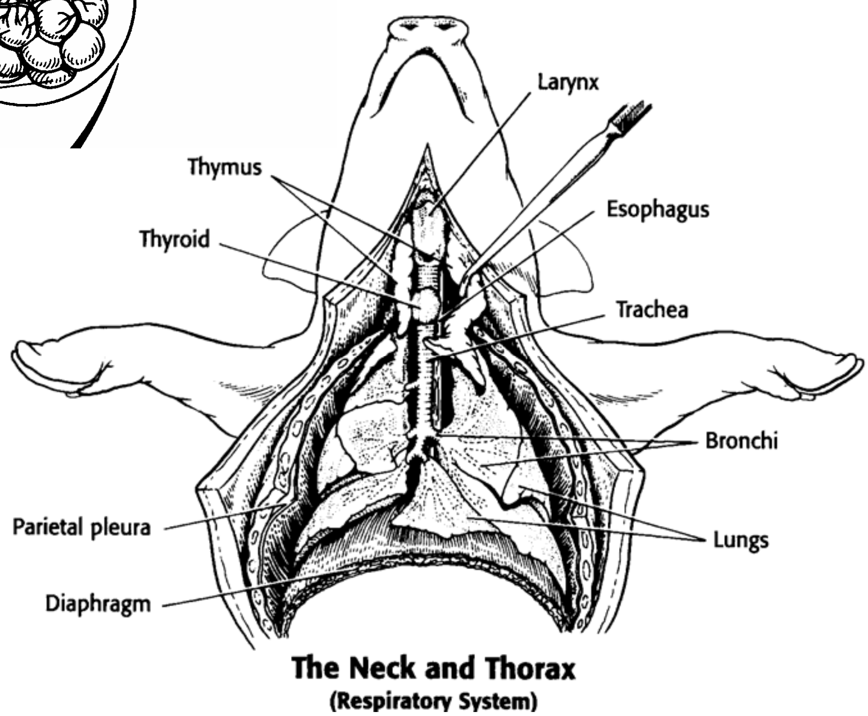


Figure 10b: Respiratory system of the fetal pig, indicating major structures - trachea, lungs (bronchi), diaphragm (from Hopkins & Smith, 1997, Introduction to Zoology).

CIRCULATORY SYSTEM (MOVEMENT OF FLUIDS)

Textbook Reference Pages: pp. 1047-1052

When you look at the vertebrate circulatory systems, you should pay particular attention to the differences in metabolism between organisms. With the increase in body size between ectotherms and endotherms and the increase in oxygen demands, also comes an increased need for the vascularization of tissues. The implications of this are massive - whereas simple pumps can work to force blood through the tissues of a fish with relatively low metabolic demands, a horse (and other mammals and birds) need a double pump system to force the oxygenated blood through the increased vessel system that comes with endothermy.

You will not have the opportunity to look at blood today, but be sure to look at the vertebrate hearts and major blood vessels and think about the issues raised above. In addition, focus on the relationship between the respiratory and circulatory systems, to understand the implications of the increase in separation between the pulmonary circuit and systemic circuit across evolutionary time in the vertebrates.

We have a number of ways for you to explore how vertebrates have solved the problem of transporting gases and nutrients throughout the body. To compare the organization of vertebrate hearts, examine the resin prep of the hearts from a fish, frog, snake, bird, and rabbit. Use pages 1047-1049 from your text to understand the flow of blood through these different hearts, and think about the increasing metabolic demands from fish to mammals and the development of a separate pulmonary circuit (Figure 11).

In addition to the resin preparations of vertebrate hearts, we also have a model of a human heart and each pair of students should do a dissection of a sheep heart, using the following guidelines and worksheet. This will allow you to explore the internal morphology of a mammalian heart, to identify the important structures: the **atria**, **ventricles**, **valves** between them, and the beginnings of the **pulmonary arteries** and **aorta**. As you do this, think about the oxygen content of the blood in different regions of the heart.

To look at whole systems, look at the pre-dissected frog and the fetal pig. As you explore these organisms, try to identify the major veins and arteries in each (Figures 12 & 13, respectively), paying attention to where in the circuits oxygen content is high and where it is low. Because of the small size of the frog heart (Figure 12b), it may be difficult to identify more than the atria and ventricle.

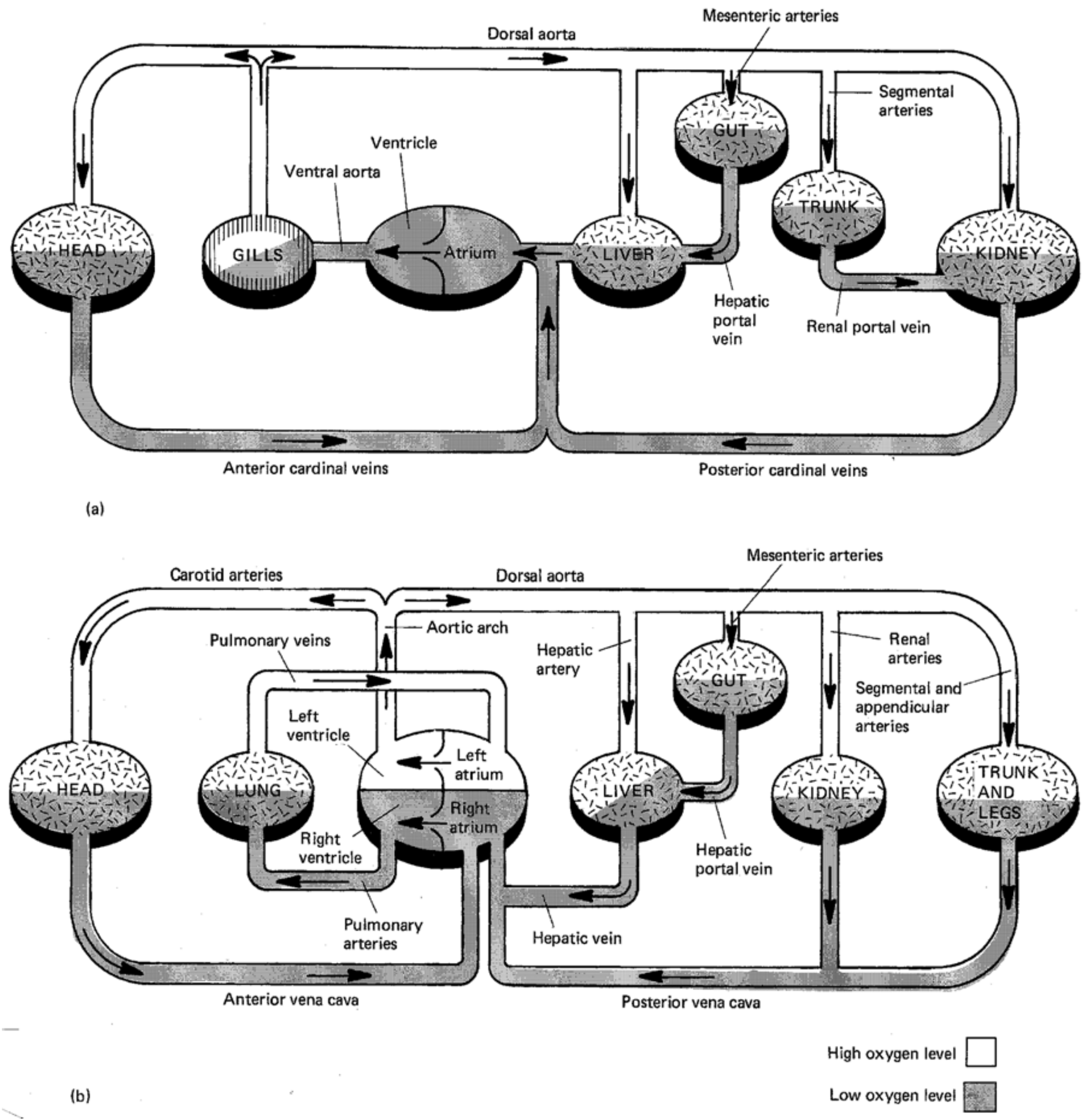


Figure 11: Circuit diagrams of blood flow through the heart and body systems of a fish (a, with a single circuit) and a mammal (b, with a double circuit). Dark shading is venous blood. (from Pough et al., 1992, Vertebrate Life, 4th ed.).

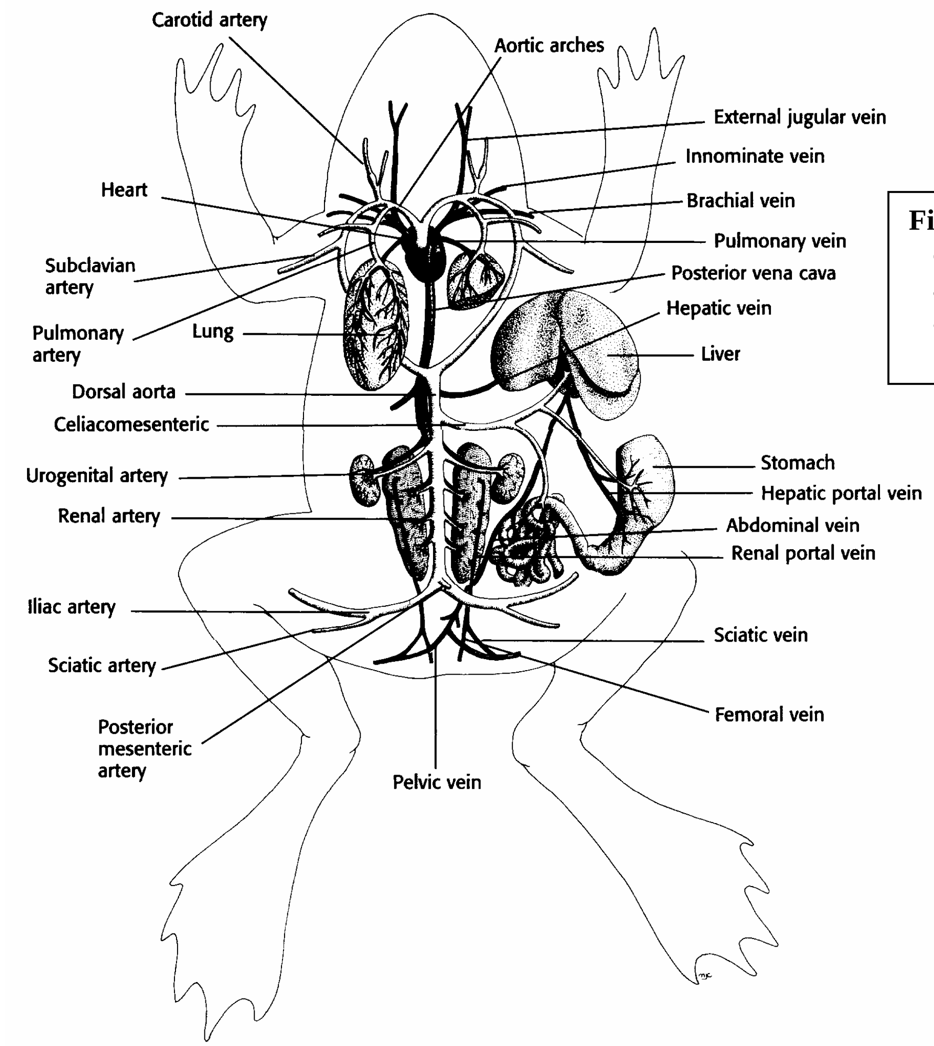


Figure 12a: Circulatory system of a frog, with arteries (light) and veins (dark) (from Hopkins & Smith, 1997, Introduction to Zoology).

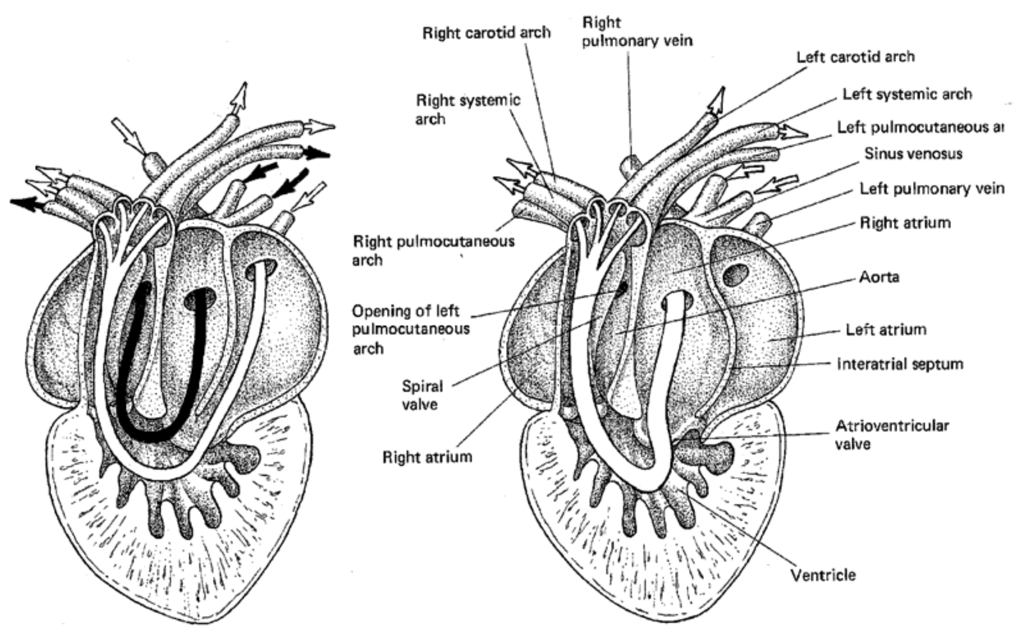
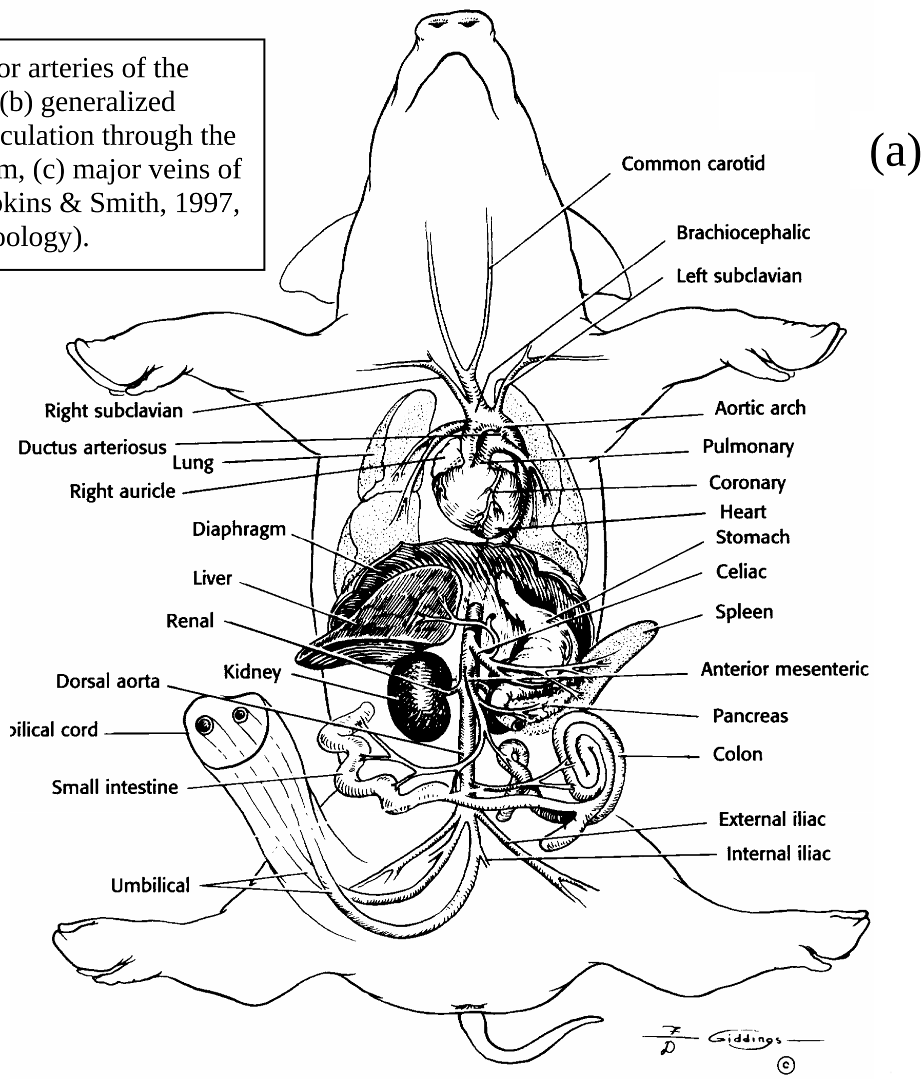
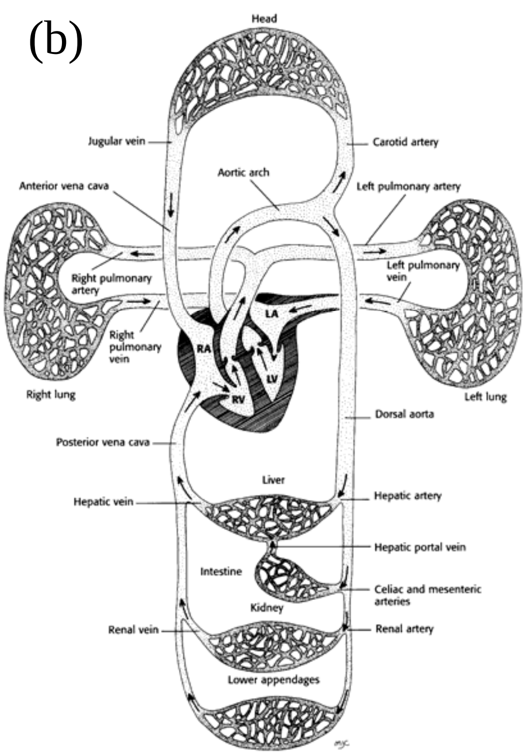
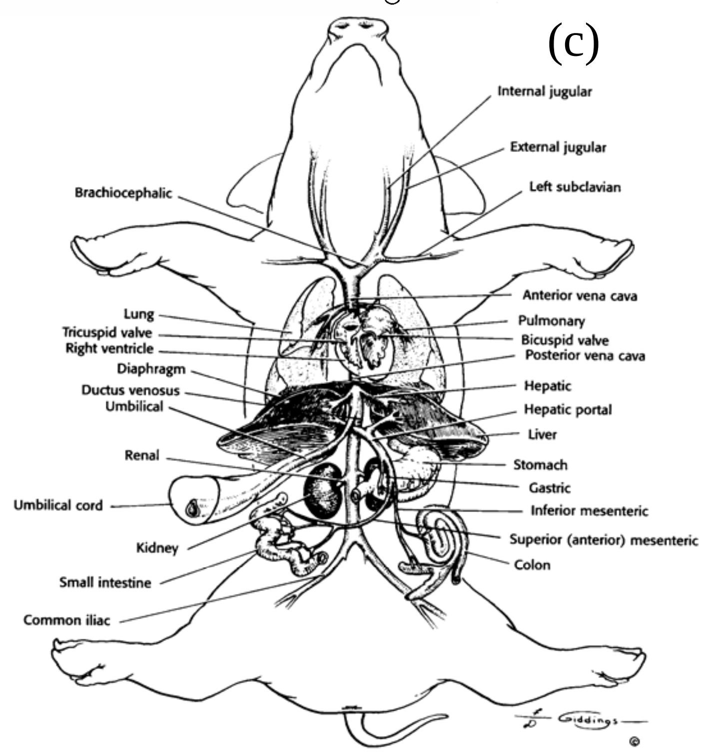


Figure 12b: Blood flow through the heart of a frog. Left, patterns of flow when lungs are being ventilated; right, flow when only cutaneous (skin) respiration is taking place. Dark arrows, blood with low oxygen content; light arrows, most highly oxygenated blood (from Pough et al., 1992, Vertebrate Life, 4th edition).

Figure 13: (a) Major arteries of the system of the pig (b) generalized diagram of the circulation through the mammalian system, (c) major veins of the pig (from Hopkins & Smith, 1997, Introduction to Zoology).







SHEEP HEART DISSECTION

In this investigation, you will examine the external and internal structures of a sheep's heart. The sheep heart is about the size of a clenched fist. It contains four chambers: two atria (sing., atrium) and two ventricles. The atria receive blood coming into the heart and the ventricles send blood out of the heart. Oxygen-poor (deoxygenated) blood enters the **right atrium** via two major veins called the **superior vena cava** and the **inferior vena cava**. The blood passes through the **right atrioventricular (AV) valve** (a.k.a. the **tricuspid valve)** into the **right ventricle**. Next, the blood is pumped out of the right ventricle into the **pulmonary trunk**, which immediately subdivides into the **right** (2) and **left** (2) **pulmonary arteries**. The pulmonary arteries transport the blood to the lungs for gas exchange. Oxygen-rich (oxygenated) blood returns to the **left atrium** via the **right** and **left pulmonary veins**. The oxygenated blood flows through the **left atrioventricular (AV) valve** (a.k.a. the **bicuspid or mitral valve)** into the **left ventricle**, from which it is pumped into a major artery, the **aorta,** for distribution to all other parts of the body. The AV valves are supported and held in position by the **chordae tendineae**. Two valves called **semilunar valves** are found at the base of the pulmonary trunk and aorta, respectively.

The efficiency in the pumping cycle of blood depends on the sequential contractions of the atria and the ventricles. The two atria contract in unison, which precedes the contraction of the two ventricles. Thus, this pattern of contractions ensures the regular flow of blood through the heart. In addition, the four valves in the heart make sure that the flow of blood through the heart is one way!

DISSECTION PROCEDURES

<u>External Views (see Figure 14).</u>

1. Rinse the sheep heart thoroughly with cold water to remove excess preservatives and to flush out blood clots.
2. Observe the **pericardium**. If the pericardial sac is intact then remove the outer layer from its attachment points.
3. Note that the heart is made up of three layers: the **epicardium** (which is the same as the inner layer of the pericardium), the **myocardium** (literally "muscle of heart"), and the **endocardium** ("inside the heart"). Carefully pull the visceral pericardium (**epicardium**) away from the **myocardium** (follow the same procedure described in step 2).
4. Examine the external surface of the heart. Notice the accumulation of adipose tissue (fat). One place the adipose tissue usually accumulates is in the **interventricular groove**, which is a good surface landmark for the internal **interventricular septum** (wall). The **coronary arteries** also travel over the surface of the heart in the interventricular groove. Remove as much adipose tissue as possible. Now you should be able to identify the **apex** (bottom left "point" of the heart) and the **auricles** (earlike flaps projecting from the **right** and **left atria**).
5. Locate the **pulmonary trunk** and the **aorta** on the superior (topmost) aspect of the heart. Clear the adipose tissue away from these arteries. The pulmonary trunk divides into the **left** and **right pulmonary arteries**. The aorta may have a large branch coming from beneath the pulmonary trunk. This branch is the **right brachiocephalic artery**. The right brachiocephalic artery divides into the **right subclavian artery** and the **right common carotid artery**. Notice the three distinct layers of all these arteries.

6. Place the sheep's heart in the dissecting tray and turn the heart so that the ventral (front) surface is facing you and the **apex** (pointed end) of the heart is pointing down with the broad **base** (superior end) of the heart facing up. Locate the **left** and **right** atria, the **left** and **right ventricles**, the entrances of the **superior** and **inferior vena cava**, and the exits of the **aorta** and the **pulmonary trunk**. Turn the heart over to its dorsal (back) surface to locate the entrances of the **pulmonary veins**. Next, use a blunt metal probe to explore the blood vessels that lead into and out of the chambers in the heart.
7. Check with your instructor or lab TA to confirm that you know all of these structures.

<u>Internal Views</u>

1. Position the heart with its ventral surface up.
2. Starting at the apex and moving towards the base, cut through the right and left edges, making a coronal (frontal) cut through the heart. Stop cutting when your knife reaches the top portions of the atria.
3. Open the heart at the apex. Now you should be able to identify the remaining structures in bold below.
4. Locate the side of the heart with the thicker outer myocardial wall. This will orient you to the left side of the heart.
5. You should see that there are spaces (or "chambers" on the left and right sides of the lower heart. These are the **left** and **right ventricles** ("ventricle" referring to something coming out of the space, which is blood in this case).
6. You should also see a thick structure dividing the two ventricles, the bulk of which is comprised of cardiac muscle. This is the **interventricular septum**.
7. The ventricles are divided from the chambers (**atria**) directly above them by **atrioventricular** (or "AV") **valves**. These valves have flaps or ("cusps") to which "heart strings" (**chordae tendineae**) attach. The left AV valve has two cusps, so it is also called the "bicuspid" valve. The right AV valve has three cusps, so it is often referred to as the "tricuspid" valve.
8. The chordae tendinae are anchored to the ventricular walls via **papillary** ("nipple-like") **muscles**.
9. You will need to cut through the rest of your heart in order to identify the remainder of the structures.
10. Look for the **aortic valve** and **pulmonary valve** at the base of the aorta and pulmonary trunk, respectively. Note: you may need to remove the right ventricular wall and cut into the pulmonary trunk in order to view the pulmonary valve. Do you understand why these valves are called **semilunar valves**?
11. Wrap your heart in damp cheesecloth and place it in a labeled, sealed Ziploc bag in a box labeled with your section day until next week. Discard of any fat scraps in the yellow trashcan.

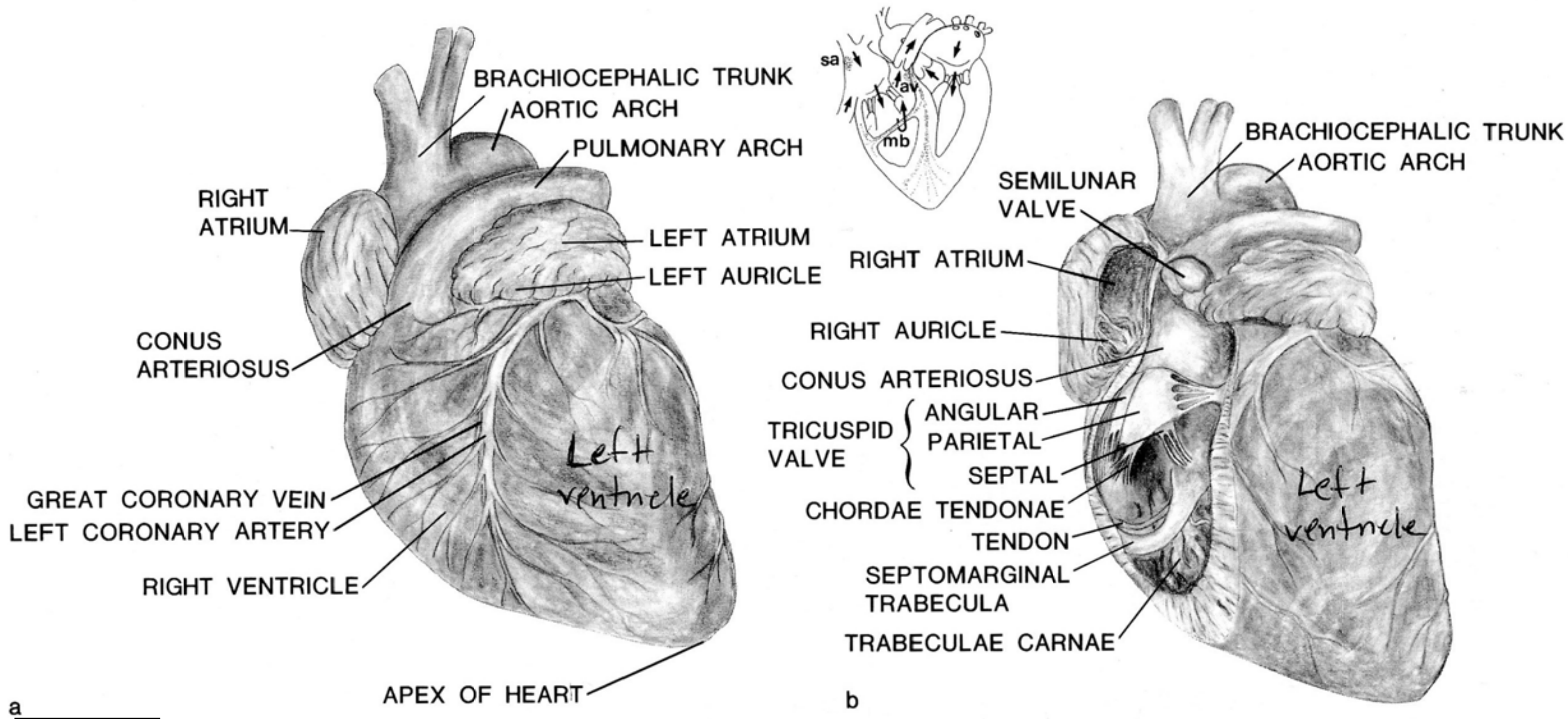


Figure 14. Various views of a sheep heart.

a. Ventral superficial view of the sheep heart. The pericardial membranes, including the visceral pericardium and the fat that normally covers the superficial blood vessels, have been removed. In ventral views, the heart is shown as if the animal were laying on its back facing the reader. Therefore, the left side of the heart is to the reader's right and the right side of the heart is to the reader's left. b) Ventral dissected view of the sheep heart. The medial tip of the right atrium and auricle has been cut off with scissors, and the right ventricle has been carefully dissected to avoid cutting the papillary muscles and chorda tendinae supporting the tricuspid valve. The left ventricle has not been dissected on this side because a dorsal dissection of the left ventricle gives better access to the aortic semilunar valve and there is less danger of cutting the bicuspid valve in a dorsal dissection. The inset diagram is a ventral view of the dissected heart with arrows to indicate the flow of blood through the heart and the position of the heart conducting system (stippled areas). SA = sinoatrial node (pacemaker); MB = moderator band; AV = atrioventricular node.

Fetal Circulation:

Gas exchange and nutrient procurement in mammalian fetuses occurs in the placenta, and mammalian lungs are not used for gas exchange until after birth. Thus, blood flow to the lungs of mammalian fetuses is greatly reduced, to a level sufficient to provide metabolic support for the growth and development of the fetal lungs. Two structural adaptations are used to shunt blood away from the fetal lugs. First, much of the blood that enters the right atrium is immediately shunted into the left atrium through a hole in the atrial wall, the **foramen ovale**. Second, for blood that enters the right atrium and does pass into the right ventricle, most of it is n pumped directly into the aorta via a short vessel, the **ductus arteriosus**, which connects the pulmonary trunk to the arch of the aorta. Study Figure 15 to be sure that you understand the differences between fetal and post-natal circulatory pathways in mammals. You should also be able to find the ductus arteriosus in the fetal pig if you carefully remove the fatty tissue around the large blood vessels at the base of the heart.

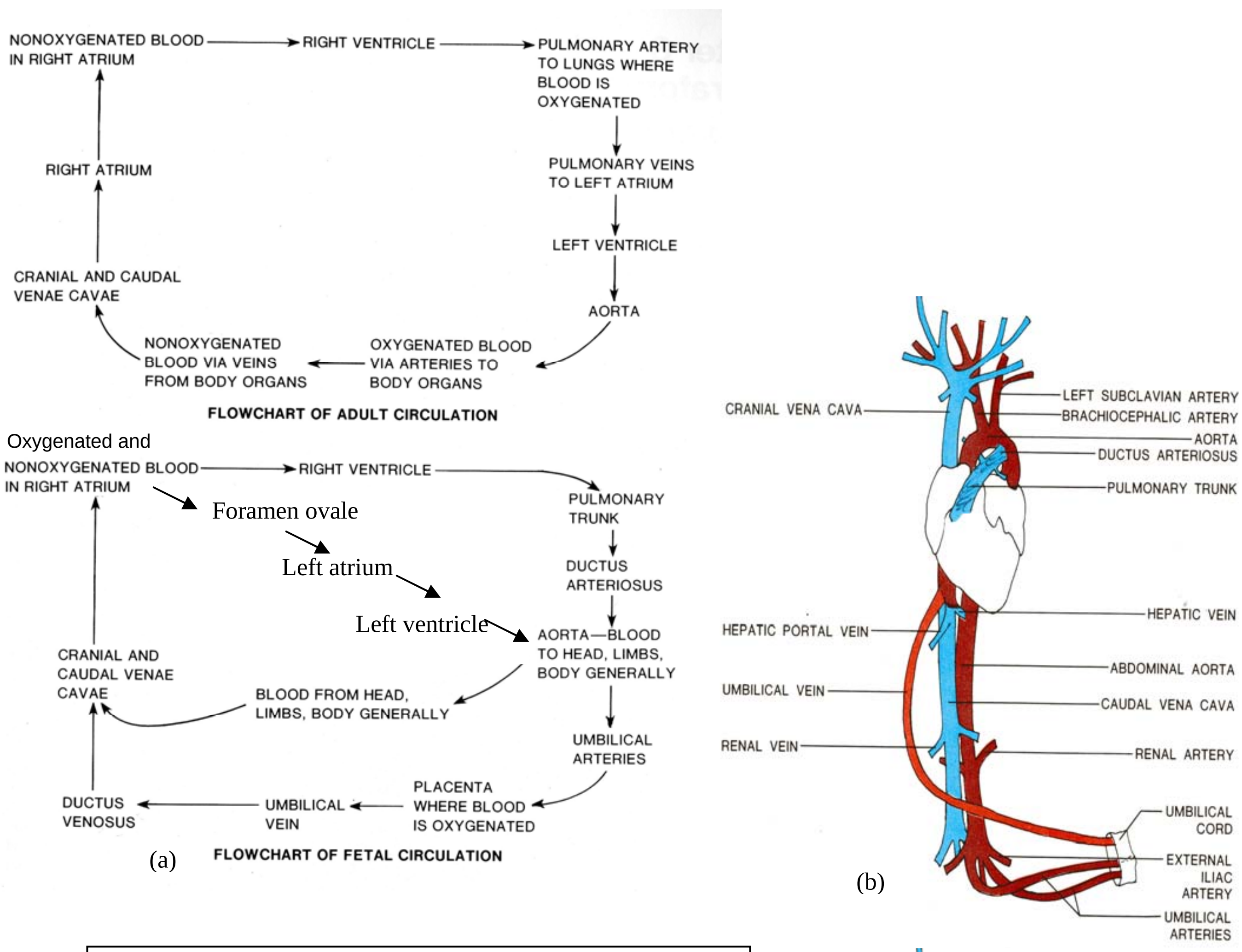


Figure 15. (a) Comparison of adult and fetal circulation. (b) Diagram of fetal circulation. (from Odlaug, 1992, *Laboratory Anatomy of the Fetal Pig*, 9th ed.)

INFORMATION PROCESSING AND SENSORY INPUT

Textbook Reference Pages: pp. 985-998 (middle)

Neurons and Nerves: Look through the demonstration microscopes to view stained examples of individual nerve fibers (e.g., **axons** of individual neurons, with their **myelin** sheath and **nodes of Ranvier** shown), **peripheral nerves** (bundles of axons of nerve cells), and the cell bodies of **motor neurons** in the spinal cord.

Brains: In the vertebrates, we see the development of complex brains, with increasingly sophisticated sensory systems, and well-developed and protected nerve cords. Because neural tissue is often difficult to dissect and identify, you have a preparation of comparative vertebrate brains in resin to look at (Figure 16 has representative brains, but not the same organisms). As you examine the vertebrate brains, notice their relative complexity, which is reflected in their size and level of corticalization, or the amount of folding in the forebrain region. These two characteristics provide a higher surface area for neural processing, compared to the body size of the organism.

Please spend some time looking at these materials and thinking about the lifestyles of the different vertebrates who used to own these brains. Why is the fish brain so small and relatively smooth? Why are the optic lobes so much more prominent in the frog than the crocodile? Why do mammals have such a convoluted texture to their brains?

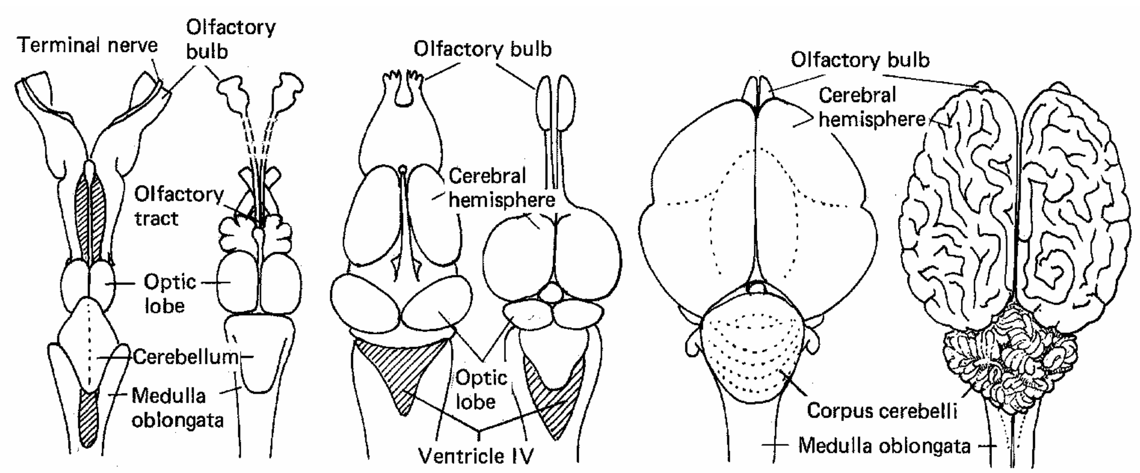


Figure 16: Representative vertebrate brains seen in dorsal view. All brains are drawn to approximately the same total length, which emphasizes the differences in regional development. From left to right, *Scymnus*, a shark; *Gadus*, a teleost; *Rana*, a frog; *Alligator*, a crocodilian; *Anser*, a goose; and *Equus*, a horse, as an example of an advanced modern mammal (from Pough et. al., 1992, *Vertebrate Life*).

Vertebrate Sensory Systems:

Vision: You may have noticed from Figure 16 that vertebrates allocate different amounts of neural tissue to visual processing. However, a striking similarity in the visual systems of vertebrates is the way in which their eyes are structured. Revisit the comparative eye diagram on p. 3 of the Invertebrate Organ Systems handout to compare the eye structures of vertebrates with the invertebrates you examined earlier in the course. Then, use the following section to guide your dissection of a sheep eye. If you find the dissections of the mammalian eye too difficult to stomach (many students find eye dissections stressful), then we have a resin preparation of a mammalian eye for you to examine. In addition, the comparative brain preparation also has eyes attached - try to get a sense of the similarities and differences in the external vision structures, the eyes and the optic lobes.

Sheep Eye Dissection

(Adapted from *Elementary Zoology Laboratory Manual*, 2nd edition,
Department of Zoology, University of Wisconsin, Madison)

We use sheep eyes for dissection because of their large size and similarity to the human eye. Refer to Figure 17 during your dissection. Study the location and general function of the structures listed in **boldface** print below.

The eyeball has much fat on its surface; this cushions it in the bony socket. Carefully clean off the fat to find the eye muscles attached to the tough, white, outer layer (the **sclera**). What are the functions of these muscles? At the <u>front</u> of the eye, observe the transparent **cornea**; this is the major refractive part of the eye in terrestrial vertebrates. Find the **conjunctiva** attached to the eyeball a short distance from the edge of the cornea. At the <u>back</u> of the eyeball, find the **optic nerve**. Is it positioned in the exact center of the posterior half of the eyeball? Press the back of the eye gently, noticing its firmness. This firmness is due to the tough, fibrous connective tissue in the sclerotic coat. What is the path that each optic nerve takes after it exits the eye?

Cut the eye in half vertically about halfway between the cornea and the optic nerve. Looking at the cut edge of the rear half of the eye wall, see that it is made up of three layers:

1. **Sclera**: The tough, white outer layer.

2. **Choroid**: Thin and black, forming the middle layer.

3. **Retina**: A filmy, whitish, inner lining containing the light-sensitive cells (**rods** and **cones**) and neural connections. Note that the retina may become detached during dissection.

All three layers are continued into the anterior half of the eyeball, where they show modifications that will be described later.

With a dissecting microscope, look into the posterior half to see how the blood vessels radiate from the same point where the optic nerve leaves the eyeball. This spot contains no rods or cones and is called the **blind spot**. The **fovea centralis**, an area with maximal concentration of cones and an absence of rods and blood vessels, is located near the blind spot, although the fovea is difficult to distinguish from the rest of the retina. Images falling on the fovea, which is at the center of the visual field, are in the sharpest focus, and color vision is best here.

Clean off the retina from a little of the inner surface and see the shiny iridescent layer (**tapetum**) on the inner surface of the choroid coat. The tapetum is not found in the human eye. In animals adapted to vision in dim light, it is thought to reflect the incident light, making it pass twice through the sensitive cells of the retina to increase the probability of its detection.

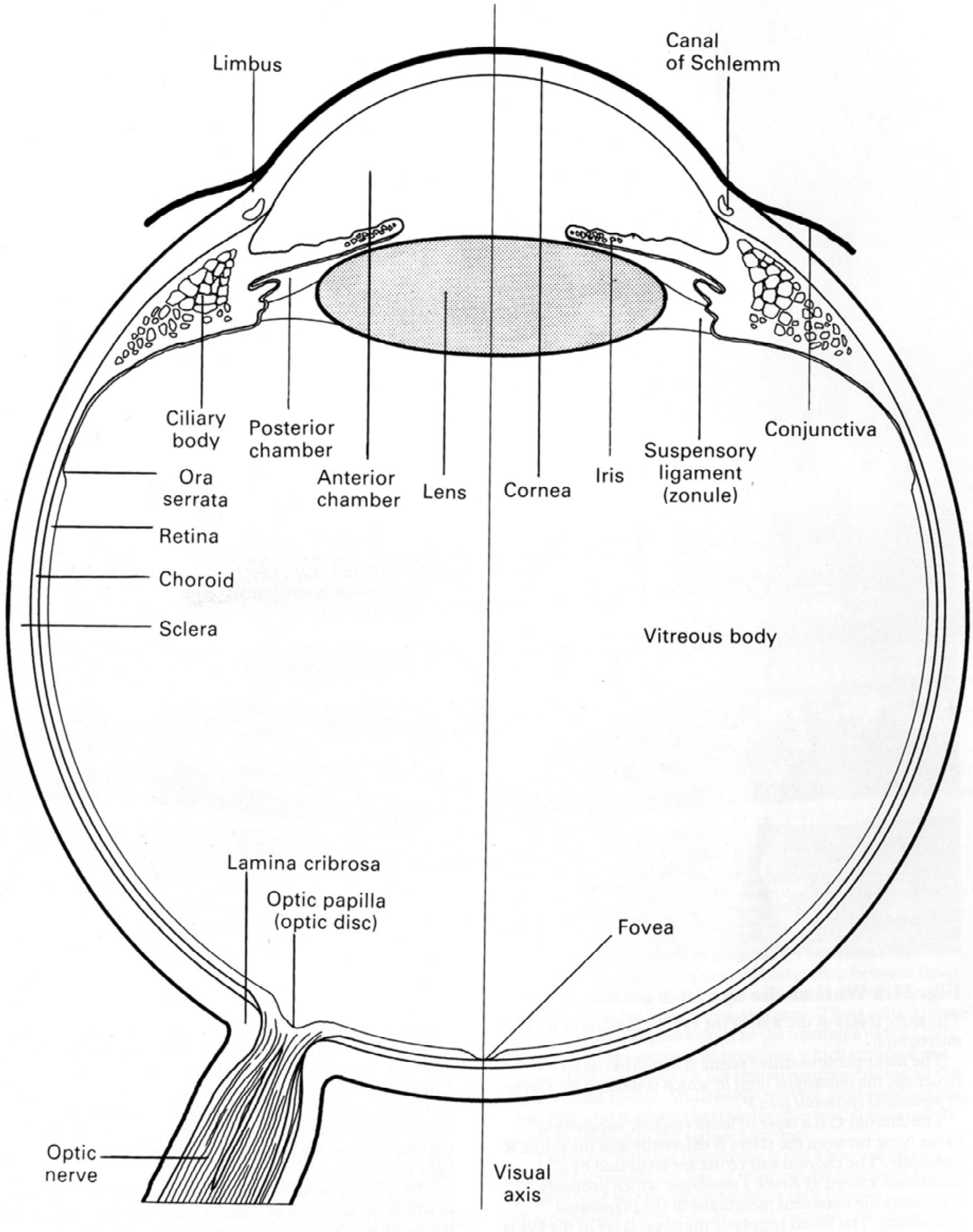


Figure 17. Diagrammatic sectional view of the mammalian eye

(from Burkitt, Young & Heath, 1993, *Wheater's Functional Histology*)

Turning to the posterior half of the eyeball, you will find it filled with the coagulated **vitreous body** or **vitreous humor,** which has pulled away from the posterior wall of the eye. It is transparent in life and composed of a gelatinous mixture of viscous liquid and delicate fibers. Remove it, noting how it adheres to the retina and choroid coat, especially in the vicinity of the outer margin of the iris. Fine fibers radiate out from the iris margin into the vitreous body.

Examine the **lens**, which helps focus images on the retina. In life it is transparent, rather soft, and readily pressed out of shape, particularly in young animals. As you remove it, notice whether the anterior or posterior surface is more convex. When the lens and vitreous body have been removed, you can see the **pupil** and the posterior surface of the **iris**. At the peripheral margins of the iris, the dark **choroid coat** is slightly thickened by internal bundles of muscle fibers, forming what are known as the **ciliary bodies**. The iris and ciliary body are forward continuations of the choroid coat. The **retina** is also extended into the front half of the eye as a thin non-sensory covering over the posterior surfaces of the ciliary body and iris. The ciliary bodies have folds on their sides that face the vitreous body and the lens. Running between the lens and the ciliary bodies are fine fibers called the **suspensory ligaments**.

The muscle bundles in the ciliary bodies have a purse-string effect when they contract, thus bringing the margins of the ciliary bodies closer to the lens, lessening the tension on the suspensory ligaments and allowing the lens to round up. A rounded lens is needed to focus close images on the retina. In contrast, to focus far-away objects on the retina, the ciliary muscles relax, the elastic tissue fibers of the ciliary bodies recoil, the edges of the ciliary bodies move farther away from the lens, the tension on the suspensory ligaments increases and the lens is flattened out. **Can you explain why people often get eye strain when reading for long periods of time and why looking out the window often helps to relieve this eye strain?**

Cut the anterior half of the eye in two, along a line running through the center of the pupil. Look at the cut edge. Note the thickness of the **cornea**, which is continuous with the sclerotic coat. The space between the cornea and the iris is called the **anterior chamber** of the eye. The small space between the iris and the lens is the **posterior chamber**. These two spaces are filled with a clear **aqueous humor** in the living eye. Near the place where the iris, cornea, choroid coat and sclera meet, look for the thickening referred to earlier as the **ciliary body**. On the inner surface of the outer margin of the iris you can see the ciliary processes. A microscopic section through this region would show short fibers of the **ciliary muscle**, which originates at the junction of the cornea and the sclerotic coat, and inserts into the ciliary body. The contraction of these fibers pulls forward on the elastic ciliary body and choroid and reduces the tension on the suspensory ligaments. This lowers the tension on the lens, which then rounds up due to its own elasticity. This produces a thicker lens that bends light rays more, thus focusing the eye on near objects.

Textbook Reference Pages: pp. 977 (bottom) - 979

Summary of Eye Dissection

A. Outer Coat
   1. Sclera
      a. Protects the eyeball
      b. Gives form and shape to the eyeball
      c. Furnishes a place for attachment of muscles to move the eyeball
   2. Cornea
      a. Transparent for transmission of light
      b. Helps focus light rays

B. Middle Coat
   1. Choroid coat
      a. Pigment prevents internal reflection of light rays
      b. Many blood vessels present to supply the retina
      c. Elastic coat: many elastic connective tissue fibers pull on suspensory ligaments and lens, tending to keep lens flattened
   2. Ciliary body
      a. Anterior thickening of mainly middle coat
      b. Contains ciliary muscle used in focusing on near objects
   3. Iris
      a. Circular and radial muscles to control the amount of light passing through the lens to the retina

C. Inner Coat

   1. Thick visual part of the retina
      a. Rods: most sensitive for light detection; no color perception
      b. Cones: function in brighter light for color perception
   2. Thin, nonvisual part of the retina; extends over posterior surface of ciliary body and iris

D. Lens: tends to round up due to its own elastic nature; kept flat by pull of elastic choroid coat and ciliary bodies on suspensory ligaments (no muscle action here!)

E. Chambers
   1. Anterior
      a. Between cornea and iris
      b. Filled with aqueous humor
   2. Posterior
      a. Between iris and lens
      b. Filled with aqueous humor
   3. Chamber of vitreous body (vitreous humor): posterior to the lens.

Other Sensory Structures*:* Sharks are renowned for their ability to detect prey. To do so, they rely upon many of the same senses that allow you to select and enjoy a meal at Valentine Dining Hall, e.g., vision, hearing, touch, taste and smell. For most of these senses, however, a shark's sense is many times stronger than a human's. For example, sharks can detect the scent of prey that are up to several hundred yards away, depending on the speed and direction of the water current (Nova Online). However, sharks have two additional types of sensory systems that make them even more efficient at prey detection. First, sharks (and other fishes) possess a **lateral line system**, which is a series of ***mechanoreceptors*** that run along the sides of the body and into the head (Figures 18 & 19). The mechanoreceptors are at the bases of water-filled tubes that penetrate the shark's skin, and they provide information about the position of the shark's body in space and about the movements of other animals in the water. They function similarly to mechanoreceptors in your own skin: if you wave your hand in a sink full of water, you can feel the water motion you create. Similarly, when swimming or wading, you can feel water movements generated by other objects or individuals moving through the water.

One class of sensory receptors that sharks have that you do not are ***electroreceptors***, which can detect the electric fields generated by other organisms (such as when a fish swims and contracts its fin and tail muscles). These electroreceptors are housed in organs called the **ampullae of Lorenzini**, which are long, gel-filled canals that penetrate into the interior of the shark's head via small pores (Figure 20). The electroreceptors detect the electric currents produced by other animals, at least over short ranges. This enables the shark to locate prey that are buried in the sand (their beating heart gives off an electrical current!), or orient to nearby movement (Canadian Shark Research Laboratory Web Site). Recent studies suggest that some sharks can detect electric fields as weak as 1.5 volts over 3,000 kilometers!

Look for the entry pores of the lateral line system and the ampullae of Lorenzini in the dogfish shark and study Figures 18-20 to understand more about these sensory receptors.

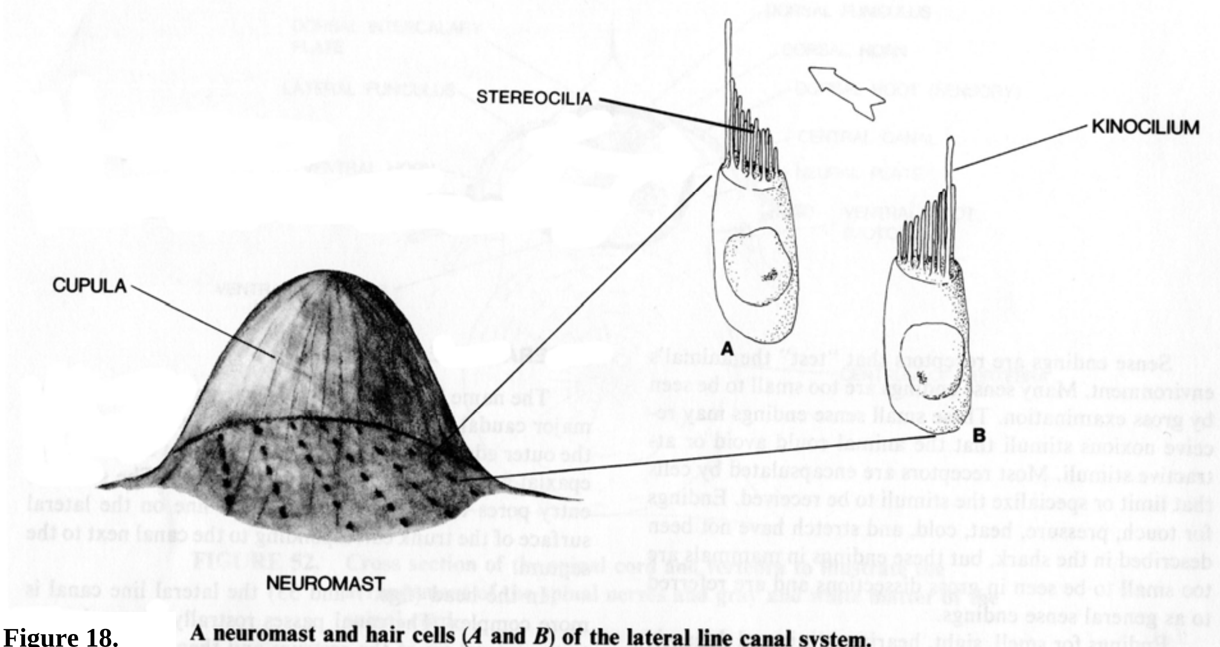
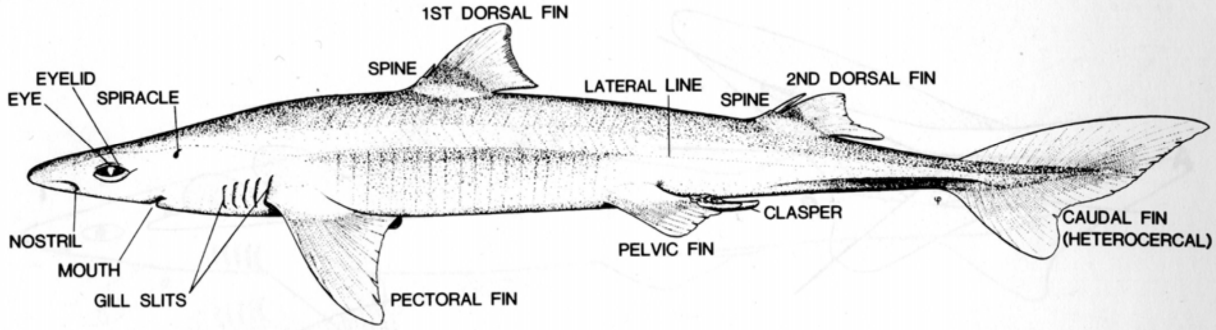


Figure 18. **A neuromast and hair cells (*A* and *B*) of the lateral line canal system. Water movement in the direction of the arrow moves the kinocilium of *A* away from the stereocilia thus inhibiting the neural activity of the cell. By the same movement the kinocilium of *B* is moved toward the stereocilia thus stimulating cell *B*. Stimulation of one cell and inhibition of the other indicates the direction of movement to the shark.**



Lateral view of a male dogfish shark.

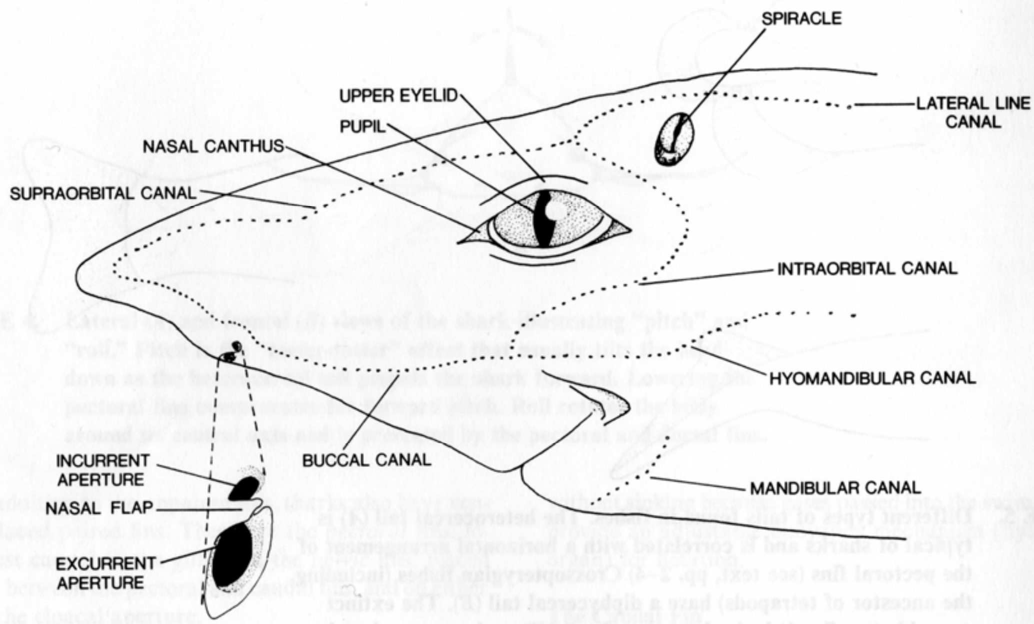


Figure 19. **Details of the external features of the head of the shark.**

(Figures 18 & 19 from Ashley & Chiasson, 1988, *Laboratory Anatomy of the Shark*, 5th ed.)

Figure 20. The dark spots in the head of this porbeagle shark are entry pores of the ampullae of Lorenzini.

EXECRETORY SYSTEM
(OSMOREGULATION & EXCRETION OF METABOLIC WASTES)

Textbook Reference Pages: pp. 1098-1105

The primary organ of osmoregulation and excretion in terrestrial vertebrates is the **kidney**. In contrast, the kidney is fairly rudimentary in structure in many vertebrates, since the elimination of metabolic wastes (e.g., ammonia) and excess salts can occur across the surface of the **gills**. To understand the movement of ions and water at these sites, it is critical to understand the characteristics of the environment. Thus, you should specifically pay attention to three issues as you look at each organism: 1) What are the characteristics of its environment? 2) How does it cope with maintaining homeostasis in terms of balancing water and salts? (does it have an impermeable skin? does it actively regulate salts? is it an osmoconformer?), and 3) What are the major structures involved in regulating water and salts? In addition, pay attention to the similarities that arise due to homology (structures derived from a common origin) and similarities that are due to convergence (like the extreme similarities in the shape of the earthworm nephridia and the vertebrate nephron).

I. OSMOTIC CHALLENGES OF LIVING IN A TERRESTRIAL ENVIRONMENT

With the move onto land, multicellular organisms were faced with being surrounded by a desiccating environment. Thus, structures that enabled terrestrial organisms to actively take up and conserve both water and ions evolved to allow these organisms to survive on land. In birds, mammals and reptiles, water and ions are ingested as part of the food and water they eat and drink. However, different strategies have evolved among terrestrial vertebrates to address the problems associated with the production and elimination of nitrogenous wastes. The kidney is the major organ for <u>both</u> osmoregulation and excretion of nitrogenous wastes in mammals. Thus, your examination of these processes in mammals will focus on the organs of the urinary tract.

A. The Urinary Tract of the Fetal Pig

1. Familiarize yourselves with the gross anatomy of the mammalian urinary tract by first studying Figures 21 & 22.

2. In the fetal pig, pull the viscera (internal organs) to either side to reveal the relatively large, bean-shaped organs along the dorsal side of the abdominal cavity. Carefully tear through and fold back the overlying peritoneum and the fat that surrounds each **kidney**. Once the peritoneum is torn, use mainly blunt dissection to examine the remainder of this system.
   a. **Ureter**: Leading from the medial side of each kidney, along with an artery and a vein, is the tube that transports urine, the ureter.
   b. **Urinary bladder**: The paired ureters drain urine into the posterior end of the elongate urinary bladder.
   c. **Urethra**: This duct extends from the posterior end of the urinary bladder into the pelvic cavity, where it enters either the penis of the male (Figure 21) or directly exits the body in the female via the **urogenital sinus** (formed by the fusion of the vagina and the urethra) (Figure 22). In the male pig, the distal urethra is a shared conduit for the urinary and the reproductive tracts.

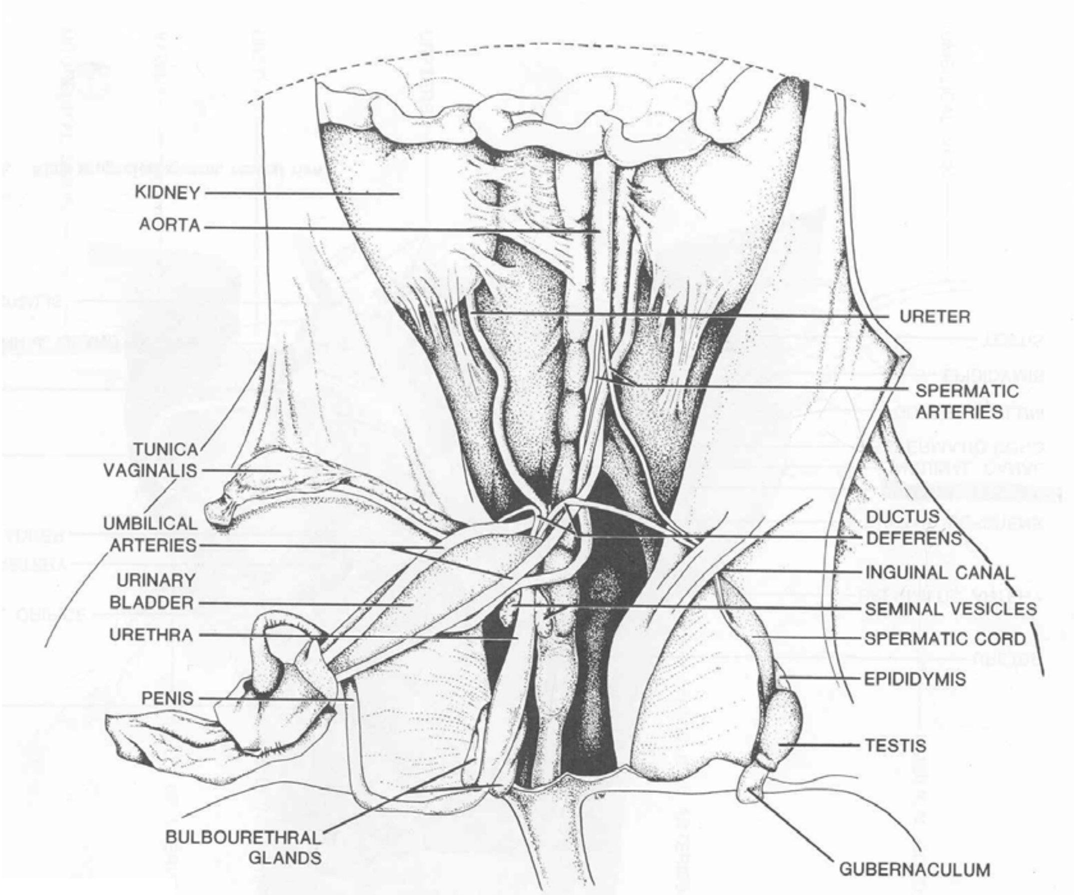


Figure 21. Male urogenital system, ventral view.

Figures 21 & 22 from Odlaug, 1992, *Laboratory Anatomy of the Fetal Pig*, 9th ed.

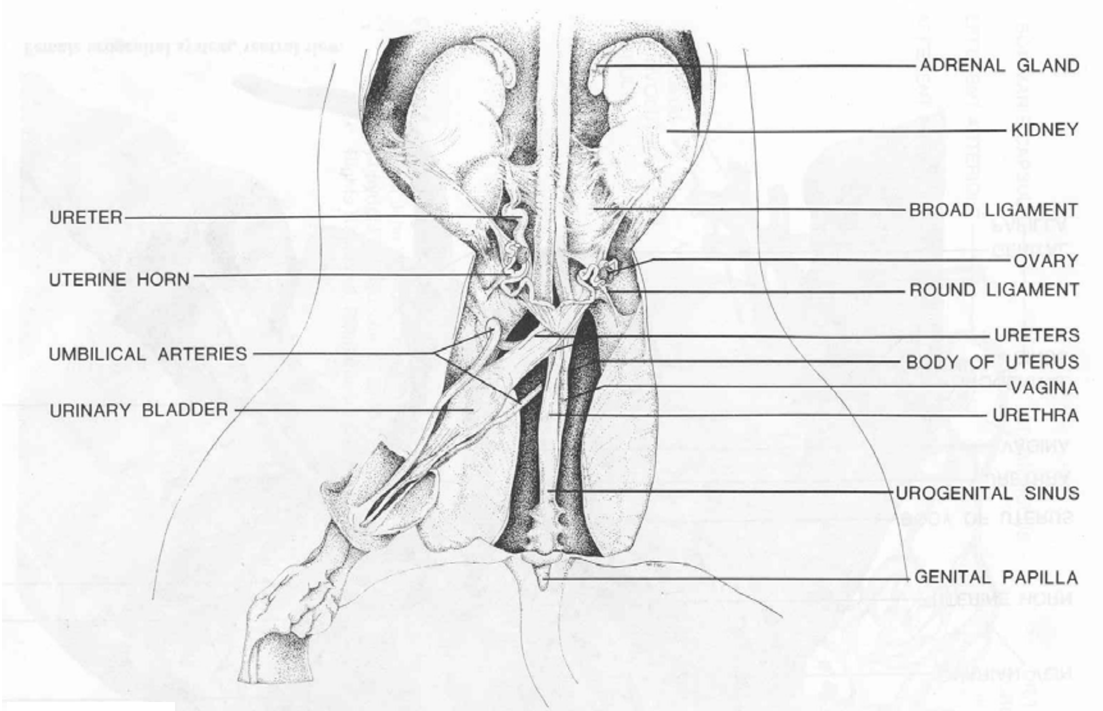


Figure 22. Female urogenital system, ventral view.

B. Mammalian kidney

Study Figures 23-24, the kidney model and the pre-dissected sheep kidney in the front of the lab. In addition, examine the microscope slide of a stained and sectioned kidney and try to identify the major parts of a **nephron**, which is the functional unit of the vertebrate kidney (Figure 23).

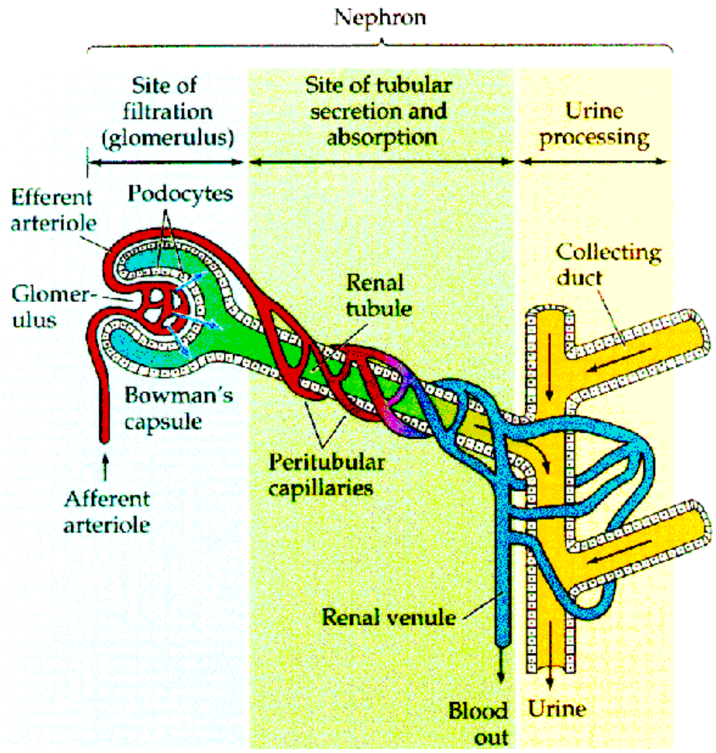


Figure 23: The generalized vertebrate nephron, indicating the sites of filtration, tubular secretion and reabsorption and urine processing (from Purves et al, 1998, Life, 5th ed.).

Examination of the Sheep Kidney

1. Examine the internal (cut) surface of the kidney (Figure 24) and note the following areas:
   a. **Renal pelvis:** This cavity is lined with whitish tissue and leads into the ureter.
   b. **Renal pyramid:** You may observe several cone-like extensions of tissue into the pelvis, the renal pyramids. They compose the **medulla** of the kidney, and urine exits from the tip of each pyramid.
   c. **Cortex**: Peripheral to the pyramids and forming a lighter-colored layer between them and the kidney surface is the cortex. The **glomeruli** and most of the kidney **tubules** are situated in the cortex.

2. Return to the diagrams and model of the mammalian kidney, and focus your examination this time on the structure of the **nephron**. The nephron is the functional unit of the vertebrate kidney, and it is thought that vertebrate nephrons originally functioned to rid freshwater vertebrates (see below) of excess water while conserving valuable molecules. Initially, body fluids flowed into the nephron from the **coelom** (the internal body cavity); subsequent evolution of the nephron resulted in its gaining the ability to filter fluids directly from the blood. Secondary adaptations that enabled vertebrates to <u>conserve</u> water must have then evolved to allow descendants of the early freshwater vertebrates to move into marine and terrestrial environments.

   Do you understand why mammals can concentrate their urine to the greatest degree of all vertebrates? This ability is directly correlated to the length of the **Loop of Henle**: the longer the Loop of Henle, the more concentrated the urine. Examine the abundant Loops of Henle in mammals by focusing on the <u>medulla</u> of the kidney, slide specimens of which are available in lab.

3. In mammals, the kidneys also function as the major organ for excretion of nitrogenous wastes, which are primarily in the form of urea (a limited amount of nitrogenous waste excretion can also occur through sweat glands in skin). Thus, the functions of osmoregulation and excretion of nitrogenous wastes are integrally related in the overall function of the mammalian kidney.

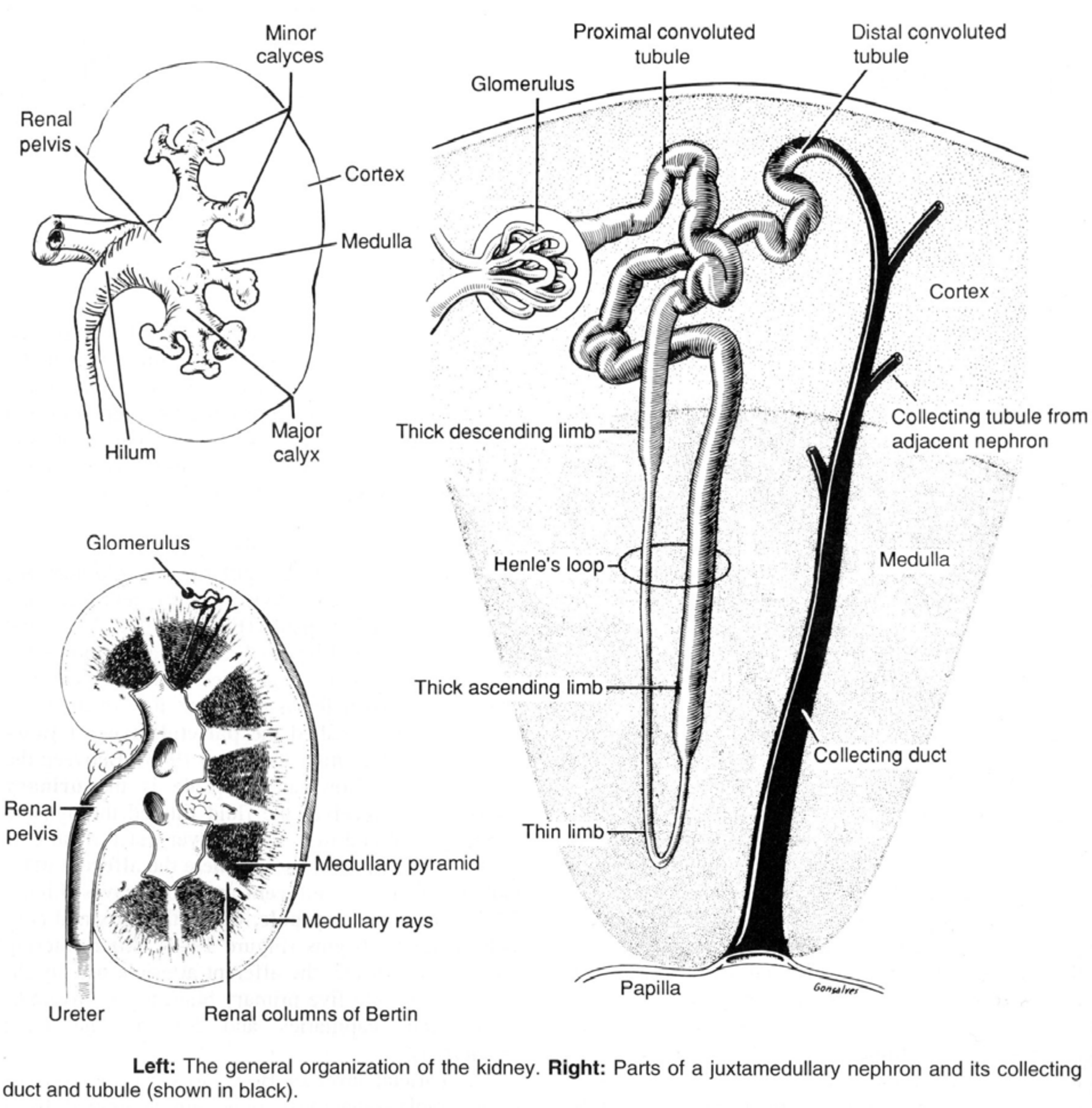


Figure 24: Major regions of the mammalian kidney indicated, with a close-up of the structure of a nephron (from Junqueira, Carneiro & Kelley, 1995, *Basic Histology*, 8^{th} ed.)

II. OSMOTIC CHALLENGES OF LIVING IN A FRESHWATER ENVIRONMENT

It is believed that the earliest vertebrates lived in fresh water. The problem facing freshwater vertebrates is that they lose salts at a rapid rate and gain water (see Figure 26 below). For example, the bodies of freshwater amphibians and fish range from 250-300 milliOsmoles (1 Osm = 1 mole dissolved particles per kilogram water), while rivers and lakes have a solute concentration of about 0-10 mOsm. As large multicellular organisms, very few cells of fish and amphibians have direct access to the external environment. Thus, these organisms eliminate the excess water they take in by using their kidneys to produce a dilute, copious urine while conserving salts.

Amphibians

1. There will be one or more salamanders (*Necturus* sp.) and a frog (Figure 25) to represent the class Amphibia available in lab. Locate and examine the kidneys in each specimen.

2. Examine the diagram of the mammalian kidney on display in the lab. Can you predict what parts of a nephron are present (or absent) in the amphibian kidney?

3. Some excretion of nitrogenous wastes occurs in the kidney of amphibians. What other organs are used for the excretion of most of the nitrogenous wastes (which are primarily in the form of ammonia and quite soluble in water) in these animals?

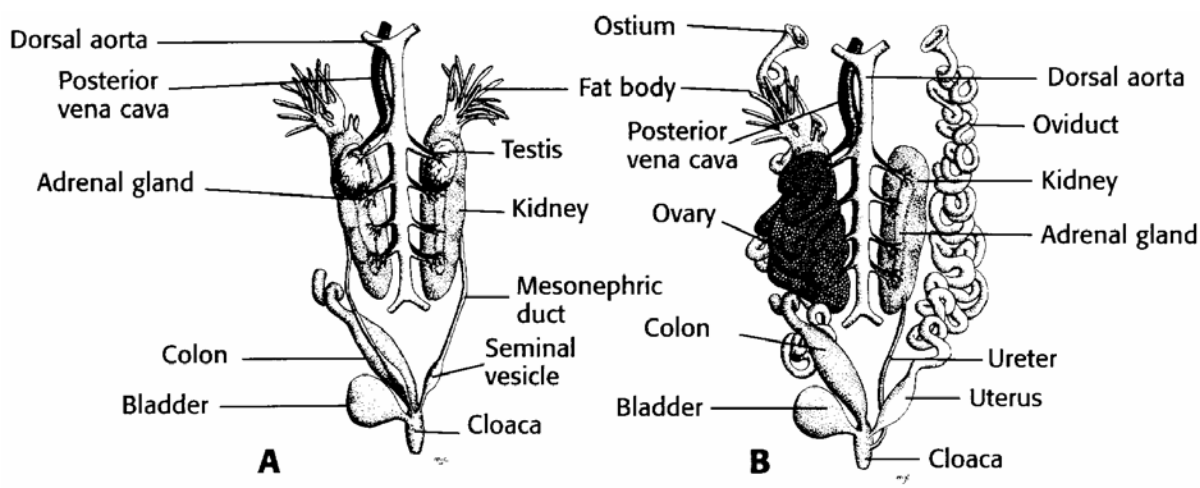
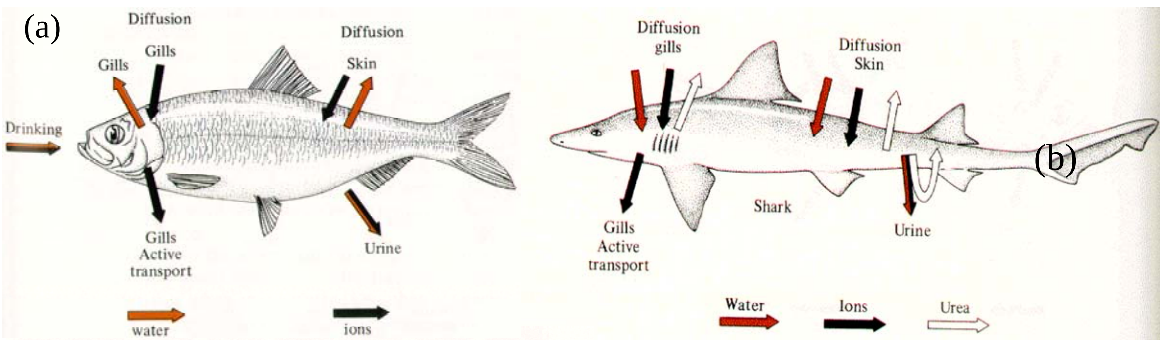


Figure 25: Urogenital system of the male (a) and female (b) frog. Kidneys, bladder, and major veins and arteries of the excretory system indicated (from Hopkins & Smith, 1997, Introduction to Zoology).

III. OSMOTIC CHALLENGES OF LIVING IN A MARINE ENVIRONMENT

Most marine vertebrates meet the osmotic challenge of living in seawater by maintaining their internal osmotic concentration *below* that of seawater. For example, most marine fish have a body solute concentration that varies from 275-350 mOsm, as compared to the surrounding seawater that has a solute concentration of 1000 mOsm. Marine vertebrates are thus faced with an osmotic challenge *opposite* to that of freshwater organisms (Figure 26). In this case, the problem is conserving water and shedding salts, because water continually leaves the gills and salts enter by diffusion. Since these organisms are surrounded by water, they have no problem finding water that they can continuously take into their bodies to replenish their water levels. However, the water they take in is very salty. Therefore, an additional osmotic challenge for these organisms is to excrete the excess salts that come into their bodies with the seawater.



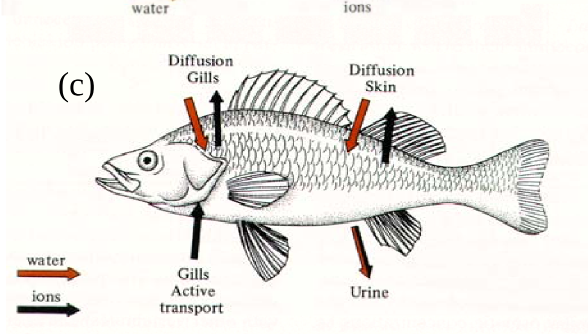


Figure 26: Major movement of water, ions, and nitrogenous waste products in a marine teleost (a), a shark (b), and a freshwater teleost (c). (from Withers, 1992, Comparative Animal Physiology).

By looking at a marine bony fish and the shark, you will examine two different ways that have evolved in vertebrates to meet the osmotic challenges of living in a marine environment. You will also see that in the shark, osmoregulation is integrally tied to the production of nitrogenous wastes. Compare both to the structure of the mammalian kidney, to think about their respective innovations to conserve water and lose salts (see Figure 26).

A. Marine bony fishes

The bony fishes (Class Osteichthyes) live in both freshwater and marine habitats. Marine bony fishes are osmoregulators. These fishes excrete the excess salts primarily through the gills. Bony fish also use their gills as the major route for the excretion of nitrogenous wastes, primarily in the form of ammonia. What behavioral adaptations do fish employ to prevent the build up of toxic wastes in the surrounding water?

Fish also have a pair of kidneys, which, as in all vertebrates, contain nephrons as the basic unit of structure. What type of urine would you predict that marine bony fishes would produce? Because water loss is a significant problem for marine teleosts, how is the kidney modified in marine bony fish to minimize water loss? It turns out that the histologic structure of the kidney of many marine bony fish is quite distinct from other vertebrates - the nephrons of these vertebrates are totally lacking glomeruli (Figure 27)! This secondary, evolutionary loss of the glomeruli greatly assists the fish in retaining water in its marine environment. Do you understand why (e.g., which process is absent in the production of urine in these fish)? The kidneys do function as an excretory organ, though, as there is some secretion of salts and ammonia into the nephron tubule for excretion in the urine.

B. Sharks (cartilaginous fishes)

Sharks have evolved an interesting way of "battling" the harsh osmotic environment of the ocean: these creatures maintain an internal environment that is slightly **hyperosmotic** to the ocean water. Interestingly, they accomplish this by using the nephrons of their kidneys to reabsorb urea, which allows them to maintain high urea concentrations in their tissues. For some as yet unknown reason, the cells and tissues of sharks are able to withstand these high levels of urea, which would be toxic to the cells of other organisms. In fact, the cells of sharks require the presence of a high urea concentration in order to function properly. For example, an isolated shark heart will stop beating if it is perfused with an isotonic solution without urea.

Since the tissues of the shark are hyperosmotic with respect to the seawater, it will take on water. Therefore, the shark counters this problem by excreting a dilute urine. Can you predict how the histologic structure of a shark nephron differs from the mammalian nephron? Examine Figure 27 below to see if you were correct! Now, locate and examine the kidneys in the dogfish shark.

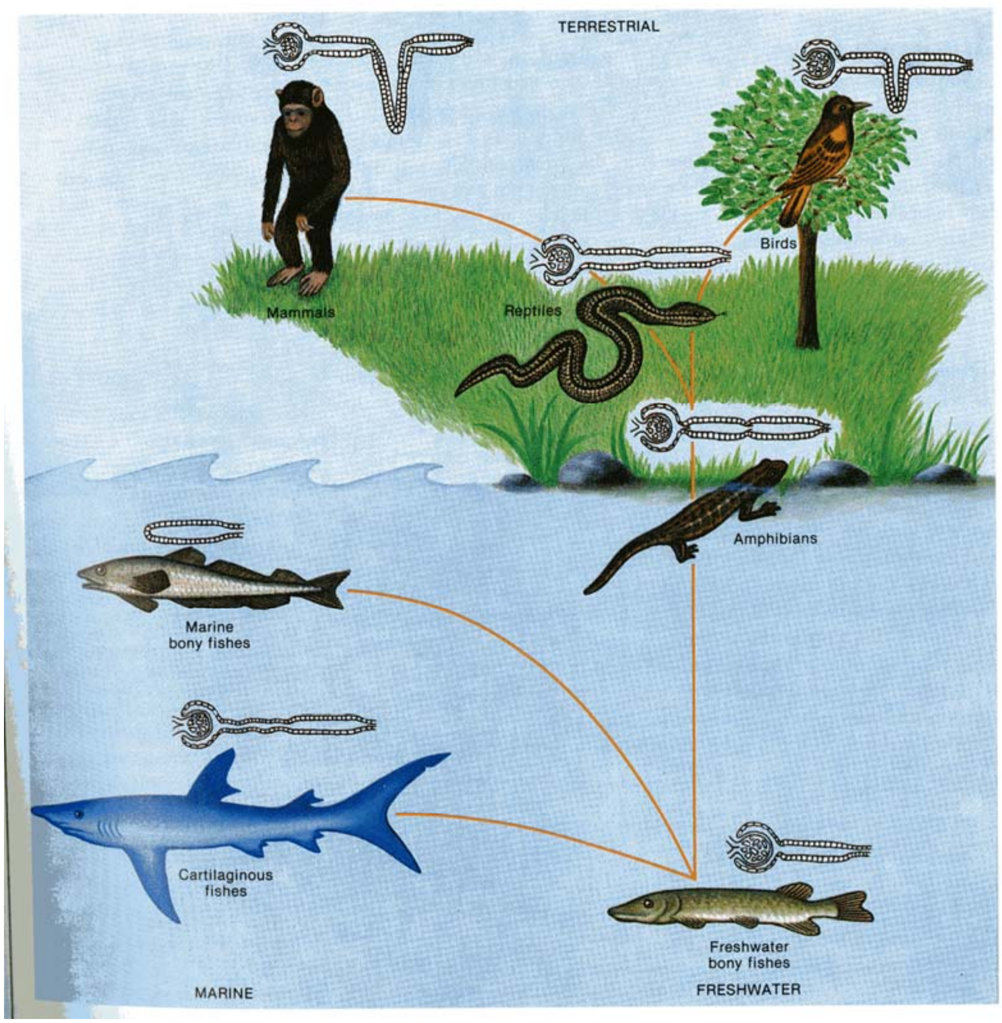
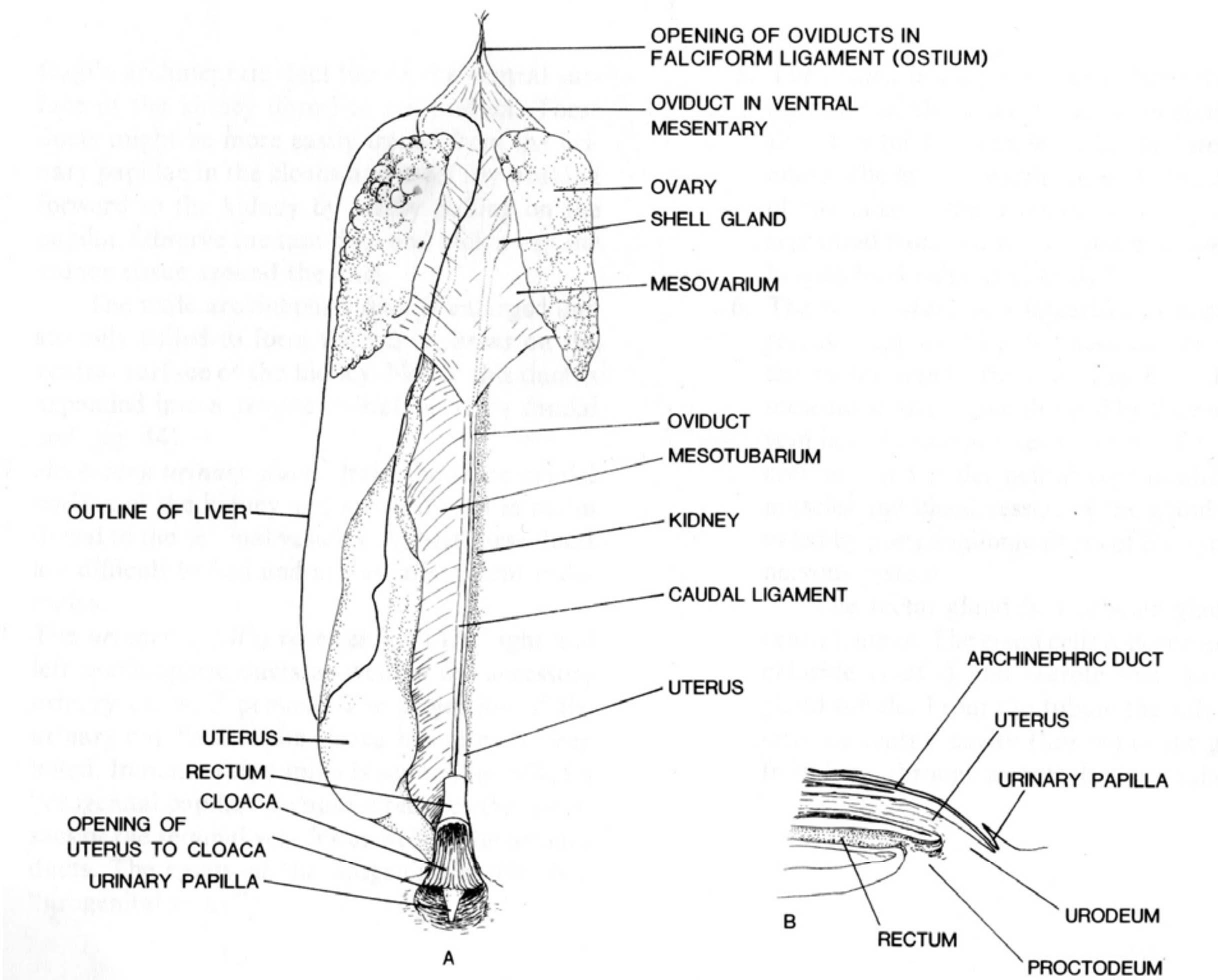
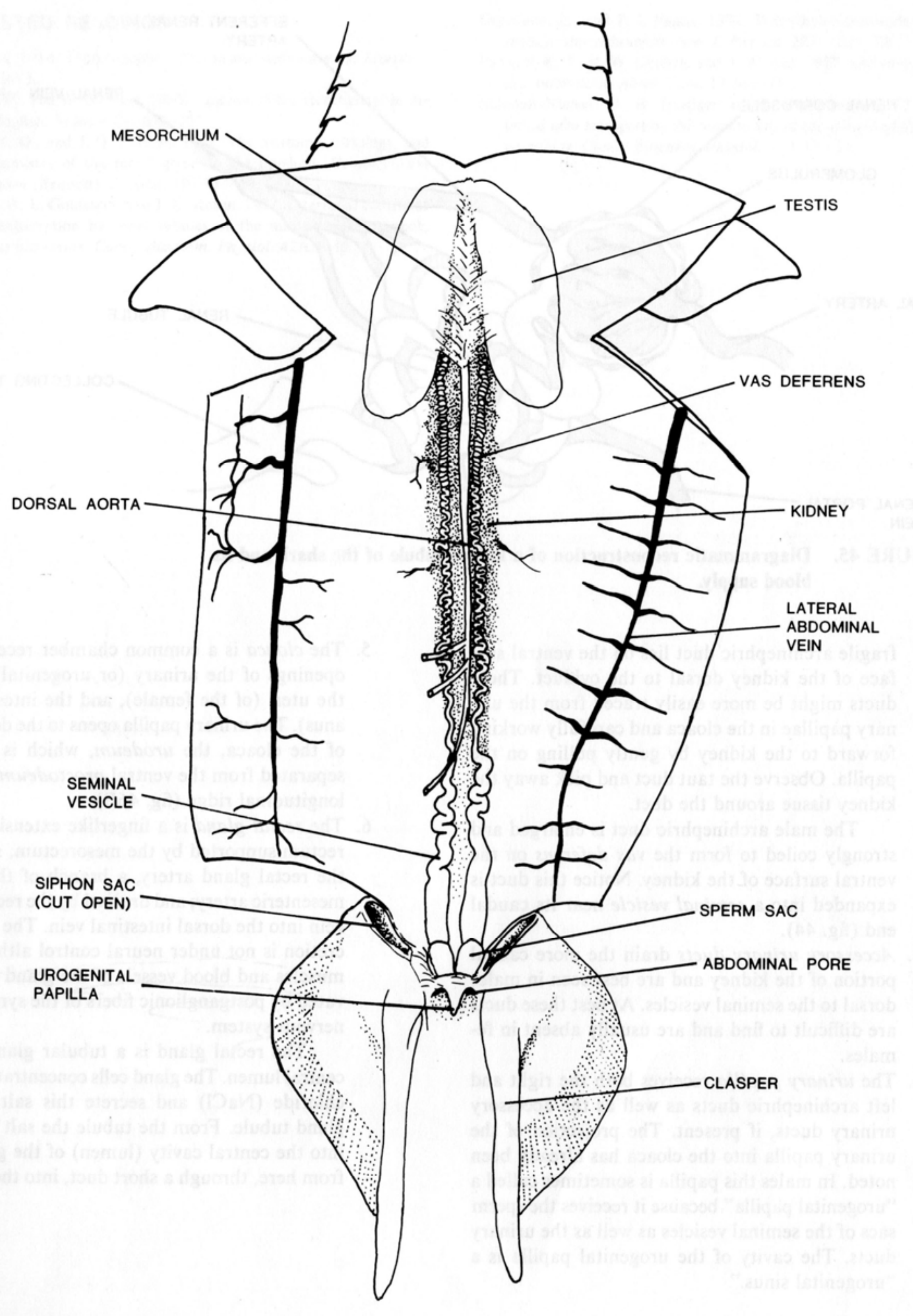


Figure 27. Variations in nephron structure among various vertebrates. Lines represent evolutionary relationships (from Harris, 1992, *Concepts in Zoology*).



Ventral diagrammatic views of the pregnant female shark (*left*) and nonpregnant (*right*) female genital system. Inset figure *B* is a diagrammatic sagittal view of the female cloaca.

This figure and next from Ashley & Chiasson, 1988, *Laboratory Anatomy of the Shark*, 5th ed.



Ventral view of the body cavity of the male shark illustrating the urogenital system.

Vertebrate Organ Systems Lab, Part I:
Circulatory, Respiratory and Digestive Systems

You will examine the above three systems the first week, saving the excretory system, nervous system, internal reproductive organs and all of the shark systems until next week. We suggest that you use the mammalian system (e.g., the fetal pig, sheep heart and pluck) as your "baseline" today, and you should be able to do the following exercises with the mammalian systems.

1. Trace the path of a red blood cell from a capillary bed in an organ of your choice through your circulatory system and back to your starting point. Make sure that you include the specific route the red blood cell takes through your heart in this pathway.

2. Trace the path of a molecule of oxygen from the air in the room into a capillary bed in one of your lungs. Describe what happens to the air that the oxygen molecule is in as it moves through your respiratory tract. What forces and accessory structures/organs are used to propel air into and out of your lungs?

3. Trace the path of a cheeseburger with lettuce and tomato on a bun through your digestive tract, explaining what happens to the food and nutrients therein at each step of the way.

In addition, ask yourself (by looking at the three stations) how these systems differ in other animals. The questions that follow will more specifically guide these comparative analyses. The list of questions is not exhaustive, but should direct your attention to specific key points of the different systems you will see today. Some questions will require that you synthesize information from lectures, your book **and** the lab.

Circulatory System:

1. What are the three major components of circulatory systems?
2. How does the pathway of blood transport differ between fish, amphibians, reptiles and mammals/birds?
3. Why might it be advantageous for an amphibian to have a single ventricle (rather than birds and mammals, which have 2 separate ventricles)?
4. What are the main differences and similarities between the circulation pattern of a fish and a mammal? Where is the oxygen content high and where is it low in these organisms?

Respiratory System:

1. By what process does the exchange of gases across a respiratory surface occur?
2. What are the three factors that evolution has acted upon to increase the efficiency of gas exchange across respiratory surfaces?
3. What are two major differences between breathing in water and breathing in air? Can you name more?
4. How does a countercurrent exchange system work? How is it different from co-current, crosscurrent (birds), or pooled (mammals) exchange systems?
5. How are the gills of the mudpuppy similar and different from fish gills? Are they as branched (do they have as much surface area)? How about the diffusion distance - is the skin over their gills thicker than the skin over fish gills? Do you think these gills work by countercurrent exchange? Do they have to?
6. What methods of gas exchange do amphibians use?
7. Reptiles have dry, scaly skin and thus cannot exchange gases there - one thing they lost in the transition from the water to land. As a result they had a dramatic increase in lung surface area with increased compartmentalization. What other problems did reptiles have to contend with when they left the water?
8. Does the lung tissue itself look different between the sheep and the bird? Can you trace a breath of air through the lungs of a bird? What are the major differences in the air circulation between birds and mammals? Which is more efficient at exchanging gasses?

Digestive System:

1. What are the three major processes that occur in the digestive system? Where do each of these processes occur?
2. How do the other organisms (other than you) process their food? What structures act like teeth to manually break down food particles?
3. The small intestine is the site of major absorption in all of the organisms you see in lab. How convoluted is it? What are the implications of increasing the length (and/or surface area) of the small intestine? Do you notice any evolutionary trends in the complexity of this structure?

Vertebrate Organ Systems Lab, Part II: Nervous, Excretory and Reproductive Systems

This week, you will focus on the nervous, excretory and reproductive systems of vertebrates. Each row of students will also receive a dogfish shark, in which you should consider these three systems, as well as the three systems studied last week (circulatory, respiratory and digestive) in other vertebrates. As last week, we suggest that you use the mammalian systems (e.g., the fetal pig, sheep kidney and sheep eye) as your "baselines" today, against which you compare the systems of other animals. You should be able to do the following exercises with the mammalian systems.

1. Trace the path of a molecule of urea (which was released from a hard-working cell, has passed through the heart and is now in the aorta) from the blood to its ultimate excretion out of the body in the urine.

2. Trace the path of an image through the eyes to the visual centers of the brain.

In addition, ask yourself (by looking at the two stations) how these systems differ in other vertebrates. The questions that follow will more specifically guide these comparative analyses. The list of questions is not exhaustive, but should direct your attention to specific key points of the different systems that you will see today. Some questions will require that you synthesize information from lectures, your book **and** the lab.

Nervous System:

1. In vertebrates, is the central nervous system (e.g., brain and spinal cord) dorsally or ventrally located?
2. Which organism has the most cortical folding in the brain? Which the least? What does this indicate to you about the complexity of the neural processes in these two organisms?
3. Which animals lack cerebral hemispheres? Why?
4. Why are the optic lobes so much more prominent in the frog than the crocodile?
5. From Figure 4 on p. 3 of the Invertebrate Organ Systems handout, Figure 17 on p. 25 of the Vertebrate Organ Systems handout and your observations from the sheep eye dissection, what are the major structural differences between image-perceiving eyes and simple eyes? Which invertebrate has a structurally-analogous eye to the vertebrate eye?
6. What specialized sensory organs do sharks have?
7. What material allows for the rapid conduction of electrical impulses along axons?
8. To where do the axons of motor neurons in the spinal cord project?

Excretory System:

1. Why might osmoregulation be important for an animal that inhabits freshwater? For an animal that inhabits saltwater? How have vertebrates today solved the problems of osmoregulation (e.g., what structures are involved)?
2. How might fish that migrate between fresh and salt water osmoregulate?
3. How does the average size of glomeruli differ between vertebrates in freshwater and saltwater? Why do you think this pattern exists?
4. Which organisms are able to produce hypertonic urine, relative to the concentration of their body tissues? What structural adaptation do these organisms have that enables them to concentrate their urine?
5. What are the major patterns of nitrogenous waste excretion in vertebrates? What are the benefits and costs associated with each method of dealing with nitrogenous wastes?
6. What is different about the regulation of urea levels in sharks?
7. How is the structure/function of a nephridium of an earthworm the same as a nephron in the mammalian kidney? How is it different?

Reproductive System:

1. Trace the path of sperm from its production out of a male pig.
2. Where are the gonads in a male pig (and other mammals, including humans)? Why are they there?
3. Trace the path of an egg from its production, to its fertilization, development and subsequent birth as a piglet in the female pig. How does this pathway differ in a human female?
4. Compare and contrast the reproductive system of the dogfish shark to the pig. How does a male shark hold on to a female shark during copulation?

Guidelines for the Laboratory Practical Exam
on April 29 & 30 and May 1 & 2, 2008

Format:

The final week of the animal diversity laboratory sequence will consist of a practical exam, which will be restricted to questions on vertebrate organs systems. In this practical exam, you will be asked a variety of questions having to do with materials that you've seen in lab during the weeks of April 15th and April 22nd. These materials may include external views of a vertebrate or vertebrate organ, internal dissected views of the same, models, diagrams, microscope slides, photographs, etc. The lab will be set up to have ~15 stations; one half the class will take the exam at 2 PM and the other half will take the exam at 3:30 PM. At each station, you should read the question and carefully examine the visual material. When applicable, identify the pinned structures (e.g., "A" or "B"), structures at the tip of a microscope pointer, and/or answer any question by filling in the answer sheet. Most questions can be answered in just one to a few words. All students will have the same allotted time per station (3-4 minutes), and there will be a 15-20 minute open walk around at the end of the exam, when you can go back to any station for another look.

Content

All information in the ***Lab 9: Vertebrate Organ Systems*** handout (including reference pages in the Sadava textbook) is fair game for an exam question. Admittedly, this is a lot of material. So, we recommend that you consider the following questions, as well as questions in the lab handout and the two study guides on pages 39-42.

1) What kind of animal is it (e.g., to which vertebrate class does it belong)?

2) How can you tell? What distinguishes animals in that class from animals in other vertebrate classes? What doesn't?

3) What are the organs and their functions (in order of action) of the mammalian digestive tract? What are the functions in digestion of the associated salivary glands, pancreas, liver and gall bladder, all of which are attached by ducts to the digestive tract?

4) What does the animal eat and what features of its digestive system make it well suited for that diet?

5) How is gas exchange accomplished in the organism? What features of its respiratory surfaces make them well suited for gas exchange?

6) What organs does air pass through to get into (or out of) the lungs of a mammal? What organs assist in mammalian breathing (e.g., inhalation and exhalation)?

7) How is transport of blood accomplished in the organism? What type of circulatory system (e.g., single or double circuit) does it have? What is the structure of its heart? Where is the oxygenated vs. deoxygenated blood in an adult vertebrate? In the fetal pig?

8) How is osmoregulation and excretion of nitrogenous wastes accomplished in the organism? What is the route of urine out of the body of the organism?

9) How does the structure of the nephrons (the functional units of the kidney) reflect the particular environment in which that vertebrate lives?

10) How is the nervous system arranged in the animal? What specialized types of sensory systems does the organism have? How does the mammalian eye work?

11) What is the structure of the reproductive system in the male and female pig vs. shark?