Introduction to the Study of Anatomy, and the External Anatomy and Integument of Representative Vertebrates

LABORATORY 33

OVERVIEW

This laboratory introduces the topic of **anatomy**, the field of science that studies the structure and arrangement of the parts of an organism. Laboratories 33 through 36 examine the anatomical features of four vertebrates, focusing on structural adaptations that illustrate evolutionary relationships and phylogenetic trends among the vertebrates. The four animals you will study are a cartilaginous fish (a shark), an aquatic vertebrate that has retained many ancestral features; an amphibian (a frog), a tetrapod illustrating the transition of vertebrates from water to land; a reptile (a turtle), a vertebrate featuring fully terrestrial adaptations; and a mammal (a rat), possessing many of the adaptations found in the class to which we belong. (Since the phylogenetic "tree" diagram, Figure 27-II in Laboratory 27, will be important to your understanding of the relationships among these vertebrate groups, you may find it convenient to move page 27-3 to this part of the manual for easy reference.) These four laboratories will give you an overview of vertebrate anatomy and experience with dissection techniques.

STUDENT PREPARATION

Prepare for this laboratory by reading the pages indicated by your instructor. Familiarizing yourself in advance with the information and procedures covered in this laboratory will give you a better understanding of the material and improve your efficiency.

If dissection equipment is not provided, obtain the following items and bring them with you to each laboratory: one one-piece scalpel or cartilage knife, one pair of dissection scissors, one probe, and two dissection needles. Do *not* use a two-piece scalpel during these exercises.

PART 1 INTRODUCING DISSECTION: ANATOMICAL LOCATIONS

Multicellular organisms, including vertebrates, are composed of groups of interacting and cooperating organs, often with common developmental origins, which form organ systems such as the integument, the digestive system, and the respiratory system. The digestive system, for example, includes the pharynx, esophagus, stomach, intestine, liver, and other organs. Each organ is made up of one or more types of tissue (see Laboratory 32).

A variety of terms is used to describe the position of body parts or organs (or parts of organ systems) and their location in relation to specified reference points. It is important to understand these terms so that you can follow dissection directions.

Study Figure 33-I, referring to the terms in Table 33-I. Notice that there is some ambiguity in using terms such as "anterior" or "ventral" in humans because of their upright posture.

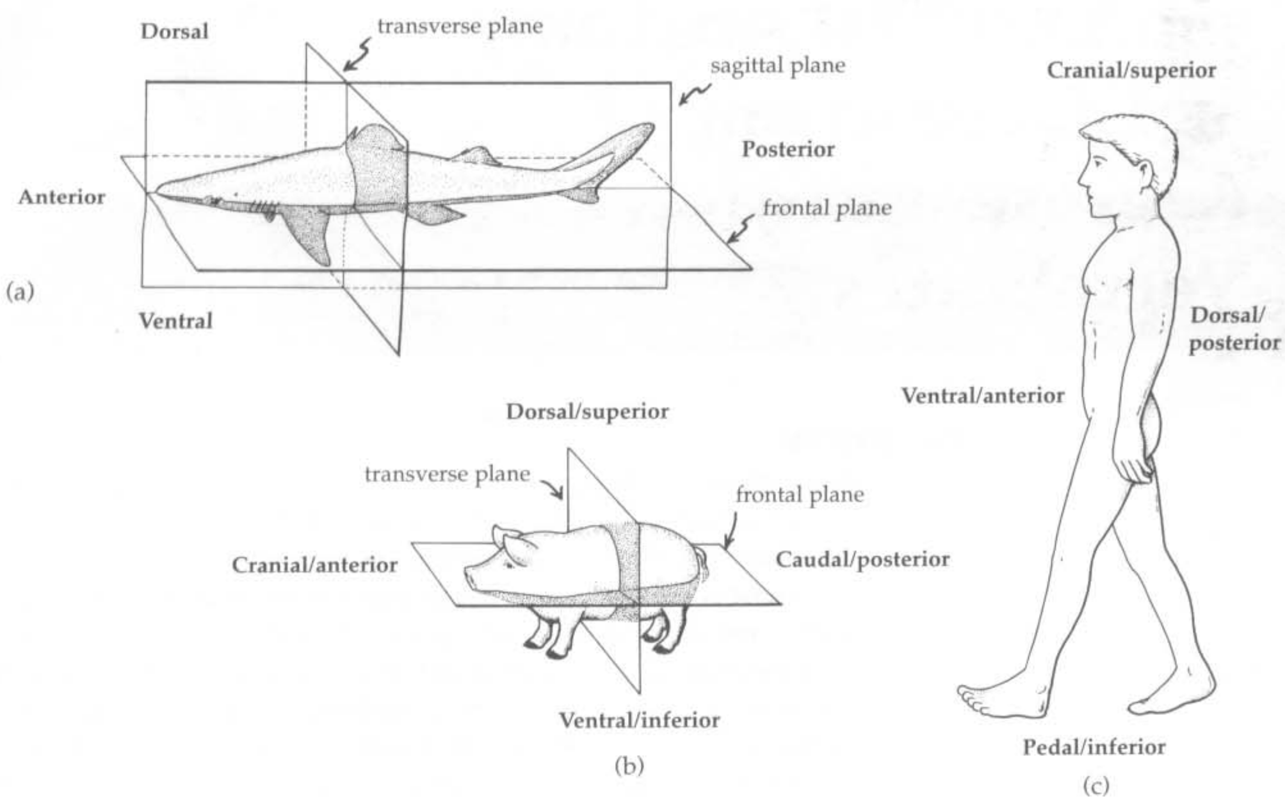

Figure 33-I *Lateral view of (a) shark, (b) pig, and (c) human.*

TECHNIQUES OF DISSECTION

Most vertebrate specimens used in dissection are preserved in a 10% solution of formaldehyde (formalin). This preservative hardens tissues and maintains their definition. However, continued storage in formalin may make the specimens less pliable and more difficult to dissect. Formalin is also irritating to the eyes, nose, and skin, and prolonged exposure is suspected to be carcinogenic. For these reasons, after specimens have been preserved in formalin, they are washed and stored in other solutions. Your instructor will tell you how to care for the specimens used in your laboratory and will inform you of any special precautions. We recommend the following:

- Always wear disposable plastic gloves to protect your hands from the solution used to preserve or store your specimen. Contact with the preservative may cause some loss of feeling in your fingers, but sensation will return within a few hours.
- Rinse your specimen with fresh water whenever you retrieve it for use and when you open the body cavity.
- Do *not* wear contact lenses. (If you rub your eyes or get any preserved tissue in them, flush your eyes with running water for 15 minutes and see a doctor as soon as possible.)

Table 33-I Definition of Terms Used to Describe Position or Direction in Vertebrates

Position or Direction	Definition
Anterior	In the direction toward which the organism faces; pertaining to the head end (in humans, equivalent to *ventral*)
Posterior	In the direction away from which the organism faces; pertaining to the end opposite the head (in humans, equivalent to *dorsal*)
Dorsal	Toward the vertebral column; the upper surface of the animal or organ; the back
Ventral	Toward the chest and abdomen; the underside of an animal or organ
Cranial	Toward the head
Caudal*	Toward the tail
Pedal	Toward the feet
Superior	Toward the upper parts of the body (in humans)
Inferior	Toward the lower parts of the body (in humans)
Lateral	Away from the midline of the body
Medial	Toward the midline of the body
Superficial	At or near the surface
Distal	Away from the point of reference
Proximal	Near the point of reference

*The word *caudal* is sometimes used to mean "toward the feet" in the human. But caudal literally means "toward the tail," and the human vestigial tail (the coccyx) is in the region of the pelvis, not the feet. For this reason we have defined caudal to mean "toward the tail" and pedal to mean "toward the feet."

- Wear old clothes for these laboratories, since some of the substances you will encounter may cause stains that are difficult to remove.

The goal of dissection is to separate body parts so that their size, shape, connections, and gross structure can be examined. To avoid damaging connections and disrupting anatomical continuity, use the scissors and scalpel as little as possible. The major use of scissors in dissection is to cut through surfaces to reach the structures beneath. When possible, try to plan cuts so that the edges can be brought back together and body parts can be reconstructed for review. The scalpel should not be used to make incisions; rather, use it as a cartilage knife to remove supportive tissues when necessary. Your fingers will be the most useful tools for separating organs and tissues. A blunt probe or dissecting needles may also be used for finer dissections.

UNDER NO CIRCUMSTANCES SHOULD ORGANS BE REMOVED FROM THEIR POSITION IN THE BODY WITHOUT EXPLICIT INSTRUCTIONS. Structures damaged prematurely may interfere with or be lost to future study. In many cases, it is advisable to work on one side of the body only, preserving the other side for later study. (This is particularly important in the case of muscle dissections, which destroy many of the blood vessels that will be traced during a later laboratory.)

You will use your assigned representative vertebrate for several laboratories, so it is important to treat it properly. If any body parts show signs of drying out during the laboratory period, wrap them with moist paper towels. After each laboratory, be sure that your specimen is stored properly. If the specimen is returned to a common bucket, be sure the animal is covered with fluid. If the specimen is to be stored in a plastic bag, moisten several towels with water and wrap the extremities and any skinned parts of the animal with the wet towels. Any parts of the animal that are to be discarded should be placed in a designated trash receptacle. Be sure to wash your hands with soap before leaving the laboratory.

ORGAN SYSTEMS OF VERTEBRATES

When we study vertebrates, it is convenient to group together organs with similar functions. These organs may show close anatomical and developmental interrelations with each other—as do many of the digestive organs—but structures serving the same function may also show major anatomical differences. For example, gills and lungs are organs of gas exchange but function in different environments—water versus air—and they are very different in structure. We will use the scheme presented in Table 33-II to study the functional associations of organs.

PART 2 INTRODUCTION TO THE REPRESENTATIVE VERTEBRATES

✓ EXERCISE A Life History and External Anatomy of Four Representative Vertebrates

Objectives

- ☐ Examine and compare the body forms of representative vertebrates.
- ☐ Locate the important external features of each specimen and be able to use these as landmarks for subsequent studies.
- ☐ Describe the major features of the life history and reproduction of the four representative vertebrates.

Procedure

Work in groups of four.

1. Put on plastic gloves.
2. One person in each group should obtain a shark, one a frog, one a turtle, and one a rat. Place your specimen on a dissecting pan.
3. As you dissect your specimen, share your observations with the other members of your group. Since the objective of this series of laboratories is to learn about evolutionary relationships and phylogenetic trends, your success in these laboratories will require that you learn as much as possible from each other's dissections. *Note*: When these labs are completed, your instructor may give you a "practical" exam; such a test requires that you be able to locate and identify structures in the specimens you have dissected. To help you to remember and review your observations, keep notes and make sketches on separate sheets. Add these to your laboratory manual.

Shark

The dogfish, *Squalus acanthias*, is a small shark in the class Chondrichthyes (cartilaginous fishes, a group that includes sharks and rays). Adult sharks and rays, unlike most other vertebrates, have a skeleton composed of cartilage, not bone. In the early stages of development, the skeletons of all vertebrates are made up of cartilage, a relatively lightweight, flexible material. In most vertebrates (including the ancestors of cartilaginous fishes), during the course of growth, most cartilage is gradually replaced by harder, denser bone tissue, which provides stronger structural support in the adult animal. However, for marine and aquatic animals, an increase in body density causes a decrease in buoyancy. The density of the ancestral fish body was higher than that of water, requiring these fish to expend relatively large amounts of energy just to keep themselves from sinking. During the course of evolution, chondrichthyian fish adapted by ceasing to replace cartilage with bone during maturation, thus reducing their overall density and also the energy required to maintain their position in the water.

In the evolutionary line leading to bony fishes (a group that includes perch, trout, salmon, and many other familiar fish), animals developed a swim bladder, an organ that contains air, thereby reducing the animal's overall density, increasing its buoyancy, and again decreasing the amount of energy required to keep from sinking to the bottom.

Table 33-II Vertebrate Organ Systems

System	Function
I. Integument (skin)	The outer covering of an organism. Provides a protective and regulatory interface with the environment.
II. Behavioral systems	Structures participating primarily in externally directed activity (behavior).
A. Sensors (affectors)	Nerve endings and sense organs that monitor both the external and internal environments.
B. Control systems*	Receive input from the sensors or feedback from other organs; produce output to structures that give rise to movement or other responses (effectors). (Adaptive responses may depend on both genetic elements and learning from past experience.)
1. Nervous system	Composed of the brain, spinal cord, and peripheral nervous system; these structures respond rapidly to input.
2. Endocrine system	An assemblage of tissues and organs with several different embryonic origins; respond to input by releasing their products into the circulatory system. These relatively slow responses may reinforce activities initiated by the nervous system.
C. Effectors	Tissues and organs that respond to stimuli to produce: movement (cilia, muscles, and muscles and bones working together), glandular secretions (gland cells and glands), light (photophores), or electrical potentials (electric organs).
III. Physiological systems	Organs participating primarily in physiological (internally directed) activities.
A. Digestive system	Processes food to provide energy and building materials for the organism.
B. Respiratory system	Functions in gas exchange; includes gills, lungs, and, in some vertebrates, the body surface.
C. Circulatory system	Carries nutrients, wastes, gases, and information-containing molecules; also has a role in disease prevention and immunological responses; serves all living tissues of the body.
D. Urogenital system	Consists of kidneys, whose functions are osmoregulation and the excretion of nitrogenous wastes, and gonads, which produce the gametes. Although these organs have very different functions, they are associated with one another during embryonic and later development.

*Note that control systems are also involved in regulating adaptive internal adjustments (physiological processes) and that both behavioral and physiological systems function to maintain an internal balance called homeostasis. During our study we will try to understand how an organism's behavior and physiology respond to external changes.

LIFE HISTORY

Dogfishes live in marine waters off the Atlantic and Pacific coasts of North America. They prefer water temperatures close to 10°C and migrate north in the spring and south in the fall, often in schools of thousands. They feed on herring, other small fishes, and squid and are themselves part of the human diet in many parts of the world. Like other sharks, dogfishes retain large amounts of the nitrogenous waste product, urea, as part of their osmoregulatory strategy. Urea retained in the body fluids helps to maintain the fluids as either isosmotic or hyperosmotic relative to seawater, thus preventing water loss to the salty ocean.

a. Explain what would happen if a shark's body fluids were hypoösmotic to seawater.

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Unlike more primitive sharks, dogfishes retain large, yolky eggs in their oviducts for a lengthy gestation period of 22 months, and give birth to live young; they are said to be **viviparous.** (Animals that do not retain fertilized eggs until hatching—they lay their eggs—are **oviparous.**)

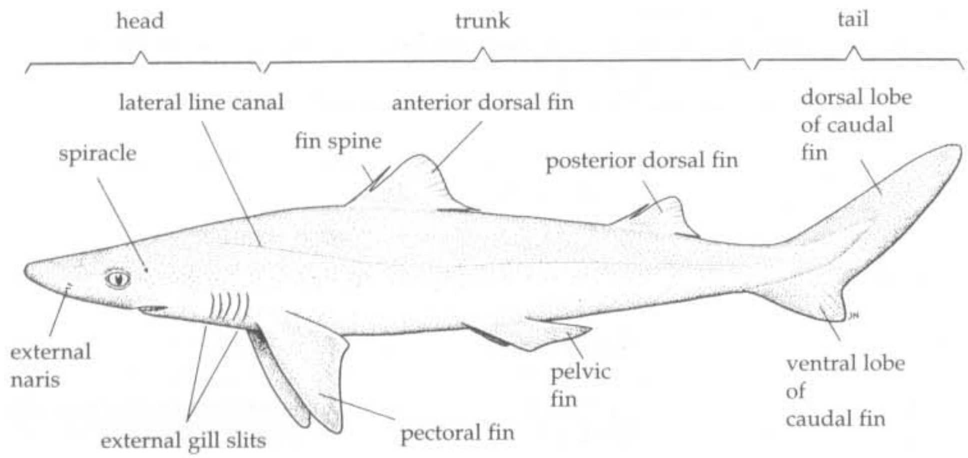


Figure 33A-1 *External anatomy of the dogfish shark.*

Procedure

1. Examine the shark. The major divisions of the shark's body are the **head,** including the gill region, the **trunk,** and the **tail.** The body shape is streamlined or **fusiform** (Figure 33A-1).
2. Pry open the mouth (if it is necessary to cut through the angle of jaw to see the teeth, cut on the animal's left side) and *carefully* feel the edges of the jaws. (The teeth are actually modified scales, derived from the dermis of the skin, and are similar to those covering the body surface.) Several rows of teeth may be apparent; the largest teeth are found on the margins of the jaws.
3. Find the **cloacal opening.** The **cloaca** is a chamber that receives products from the digestive system and from the excretory and reproductive systems.

   b. *Which of the other vertebrates dissected in this laboratory have a cloaca?*

   ____

   c. *Humans do not have a cloaca. What are some of the anatomical differences that distinguish the human urogenital system from that of animals with a cloaca?* ______________________________

   ____

4. Find the **external gill slits.** These are openings from the pharynx (also part of the digestive system) to the exterior. Water is normally taken in through the mouth, passes to the pharynx where capillaries of the internal vascular gills provide a surface for gas exchange, then leaves through the external gill slits. The **spiracles,** one behind each eye, are modified external openings of the anterior gill slits which, during the course of evolution, have been displaced dorsally by the development of the jaw. (In higher vertebrates, structures derived from the spiracles developed into the eustachian tube and middle ear.) In bottom-dwelling cartilaginous fishes such as skates and rays, water for respiration enters through the spiracles, since the mouth often rests on the bottom.
5. Examine the paired **external nares** (on the lower portion of the snout). Use the blunt end of a probe to explore these structures. Note that they are strictly external and do not open into the mouth cavity; the nares contain the olfactory epithelium, which mediates the sense of smell.
6. Find the paired eyes. Note the fleshy, nonmotile lids above and below the eyes (in some sharks, the lower lid is movable and can cover the eyeball to protect it during feeding).

7. Press gently on the skin covering the dorsal area of the snout. Note the jellylike material extruded from numerous **ampullary organs of Lorenzini** located in this region. Ampullae contain sensors of electroreception.

   d. How would an aquatic organism use the ability to sense electrical fields?

   ____

8. The **lateral line canal** can be seen as a thin, light line running along the side of the body. Sensory receptors of the lateral line provide the dogfish with the ability to sense movements in the surrounding water.

9. Identify the two dorsal fins, the caudal fin, and the paired pectoral and pelvic fins, all of which are used in locomotion. Examine the pelvic fins carefully. In males, the medial border of each fin is modified to form a **clasper** with a deep groove along its border. Folds of skin overlap this groove and close it off from the surrounding water. Anteriorly, the groove connects with a siphon sac which can fill with seawater. When seawater is pumped out through the groove, it mixes with sperm from the cloaca and travels through the groove into the cloaca of the female during **copulation.** In the dogfish, fertilization is internal.

   e. Why? ______________________________

   Note that the pelvic fins of the female are broad and unmodified.

   f. What is the sex of your specimen? ______________________________

10. Feel the surface of the skin. Its unique texture is due to **placoid scales,** which originate in the dermis and have a structure, and evolutionary origin, similar to that of teeth (see Exercise B).

    g. Placoid scales are part of what organ system? ______________________________

11. Turn to the Summary, page 33-13.

Frog

The bullfrog, *Rana catesbiana*, is a large frog in the class Lissamphibia (modern amphibians). It is an anuran—"without tail." Other living amphibians include the salamanders (urodeles) and the wormlike caecilians of the tropics. Frogs have hind legs and a pelvic girdle that are highly specialized for jumping.

LIFE HISTORY

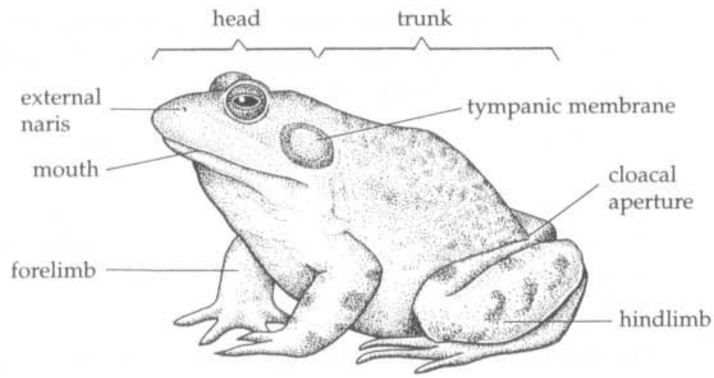
The large genus *Rana* has over 400 species worldwide and about 27 species in North America. Adult bullfrogs live in shallow, still waters from Nova Scotia to central Florida along the East Coast and west through the Great Plains. In colder climates, adults may burrow into the mud and pass the winter in an inactive, torpid state (hibernation).

When females are ready to mate, they locate a vocalizing male. A male mounts the female's back and clasps her tightly (an embrace known as **amplexus**). This action stimulates the female to lay hundreds (or thousands) of eggs which, as they emerge, are mixed with sperm from the male. Fertilization is external. Embryos develop from jelly-coated eggs and hatch as aquatic tadpoles (a larval form with external gills, no paired appendages, and a long tail). After two or more years, the bullfrog tadpoles undergo **metamorphosis,** a process that takes several months. During this time the gills become internal and are later functionally replaced by lungs. Fore and hind limbs appear and become functional locomotor organs, and the tail is reabsorbed. Tadpoles feed on plants and decaying animal material; adults eat insects, other invertebrates, and small fishes.

Procedure

1. Examine a specimen of the bullfrog (if you are studying a different species, your instructor will identify it and tell you about its range and life history). The major divisions of the body are the **head,** which extends to the shoulder region, and the **trunk** (Figure 33A-2).

Figure 33A-2 *External anatomy of the adult bullfrog.*



2. Locate the **mouth** and the **cloacal opening.** The **cloaca** is a chamber that receives products from the digestive system and from the excretory and reproductive systems.
   a. *Which of the other vertebrates dissected in this laboratory have a cloaca?*

   ____

   b. *Humans do not have a cloaca. What are some of the anatomical differences that distinguish the human urogenital system from that of animals with a cloaca?* ______________________________

   ____

3. Find the paired **external nares.** Pry open the mouth and find the **internal nares** opening anteriorly into the roof of the mouth cavity (cut through the angle of the left side of the jaw if necessary). The nares provide a pathway for the movement of air between the outside and the lungs. The olfactory epithelium responsible for the sense of smell is located along this pathway.
   c. *Are teeth present on the jaws? Describe them.* ______________________________

   ____

   d. *How does the structure of the frog's nares differ from that of the shark's nares?*

   ____

   What is the significance of this difference? ______________________________

   ____

4. Find the eyes. Both the upper and lower eyelids are nonmotile, but a third eyelid, the **nictitating membrane,** protects the surface of the eye. Locate this membrane if possible (it is better seen in the living frog). One of the extrinsic muscles of the eye is used to pull the eye deep into its orbit, further protecting it.

5. Behind the eyes, find the paired **tympanic membranes** of the ear. In frogs (and turtles) this membrane forms an "eardrum" flush with the surface of the body, separating the middle ear from the environment. In some reptiles and in birds and mammals, the tympanic membrane is recessed, separating the middle ear from the outer ear (the passage to the outside). The middle ear and outer ear develop, both phylogenetically and embryonically, from the first gill slit or spiracle (see step 4, page 33-10). (In the shark, there is no middle or outer ear; the inner ear is not highly modified for the perception of "sound" and the spiracle remains as an open gill slit.)

   The tympanic membrane **transduces** sound, changing airborne vibrations to mechanical vibrations that can be carried by the **columella,** a bone derived from the hyoid arch (part of the pharyngeal skeleton in sharks and ancestral vertebrates), to the inner ear where the sensors associated with hearing are located. In bullfrogs, the tympanic membranes show **sexual dimorphism**—they are larger in males than females.

e. Is your specimen a male or a female? ____________________

f. What major sensory system found in the shark is absent in the adult frog?

____

6. Compare the **forelimbs** and **hindlimbs.**

   g. How do the forelimbs and hindlimbs differ? ____________________

   h. What is the significance of this difference?

   ____

   i. How do the limbs of frogs differ from those of sharks?

   ____

7. Touch the skin. Can you feel scales? In most adult amphibians, the skin is moist and is richly vascularized.

   j. What are the functions of this moist, vascular organ? ____________________

   ____

8. Turn to the Summary, page 33-13.

Turtle

Turtles, descendants of the earliest reptiles, form an order within the class Reptilia. Turtles of the genus *Pseudemys,* whose members are commonly called cooters or sliders, are a favorite choice for dissection. The genus ranges from the United States to Argentina and is found in aquatic habitats including rivers, ditches, lakes, and ponds.

Male pond sliders (*P. scripta*) have long nails on their forelimbs and their shells are flatter than those of females; the females of the species are generally larger. Males have a long grooved penis that carries sperm to the cloaca of females; fertilization is internal. Usually, several shelled eggs are laid at one time. Unlike endothermic vertebrates (birds and mammals), in which the sex of the offspring is determined genetically, **sex determination** in turtles (and some other reptiles) depends upon the incubation temperature of the eggs. In turtles, higher temperatures favor females and lower temperatures, males. (The reverse is true in lizards and alligators.)

a. Why would temperature-dependent sex determination not be a good idea in birds and mammals?

____

Sliders are largely vegetarian.

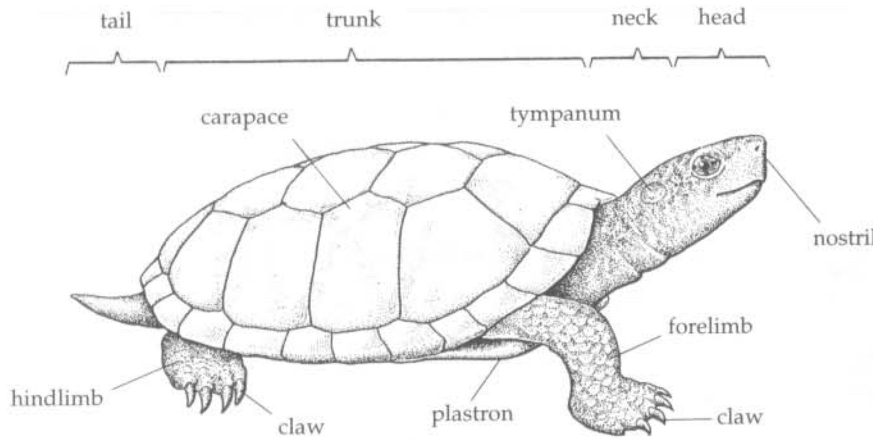
Other turtles available for dissection include painted turtles, *Chrysemys,* or snapping turtles, *Chelydra.* Your instructor will give you information about these turtles if they are used.

Procedure

1. Examine the preserved turtle. The major divisions of the body are the **head** borne on a long **neck,** the **trunk,** and the **tail** (Figure 33A-3). The major portion of the body, the trunk, is covered dorsally by a **carapace**—a combination of the axial skeleton and bony plates overlaid by scales or **scutes** (see Exercise B). The arrangement and characteristics of these scutes vary in different species and can be used for identification. Ventrally, the turtle is covered by a **plastron**—also a combination of bony plates and scales. Note the bony bridges that connect the plastron and carapace. A tail protrudes from the back portion of the body.

   b. What is the sex of your turtle? ____________________

Figure 33A-3 *External anatomy of a turtle.*



2. Locate the **mouth** and **cloacal opening.** The **cloaca** is a chamber that receives products from the digestive system and from the excretory and reproductive systems.

   c. Which of the other vertebrates dissected in this laboratory have a cloaca?

   ____

   d. Humans do not have a cloaca. What are some of the anatomical differences that distinguish the human urogenital system from that of animals with a cloaca? ______________

   ____

3. Find the paired **external nares.** Cut through the angle of the jaw on the left side and pry open the mouth. Locate the **internal nares** opening into the roof of the mouth cavity. Airborne molecules passing through this channel stimulate cells of the olfactory epithelium, which mediates the sense of smell. Are teeth present on the jaws? Are teeth present in other reptiles?

   e. What are the differences between the structures of the mouth cavity of the turtle and of the frog?

   ____

4. Examine the eyes. Note the upper and lower eyelids and find the **nictitating membrane** in the anterior corner of the eye. Find the **tympanic membrane** (tympanum), the exterior covering of the **middle ear** on each side of the head just above and behind the angle of the jaw. This structure transduces sound waves in the air into mechanical vibrations that are transmitted to the **inner ear,** where they are transduced into nerve impulses.

5. Examine the **forelimbs** and **hindlimbs.** Note the platelike scales of the skin. Feel them. Is any bone associated with them? Are they slimy? (Reptiles lack integumentary mucous glands.) Examine the **claws** on each foot. Feel them. Like the scales covering the shell, the claws are composed of keratin.

   f. How many digits are on the forelimb? ______ *On the hindlimb?* ______

6. Turn to the Summary, page 33-13.

Rat

The laboratory rat is a rodent classified in the class Mammalia, a group distinguished by the presence of mammary glands and hair. Specimens available for dissection in the laboratory will probably be either white (albino) or hooded rats.

Like all mammals, rats are **viviparous,** giving birth to live young. Unlike sharks, in which the embryonic yolk sac serves as a membrane for nutrient and gas exchange, mammals possess a true **placenta,** which provides for intimate contact of maternal and fetal blood and facilitates the transfer of nutrients, wastes, and gases between mother and fetus. Also, unlike most other vertebrates, laboratory rats (and many other domesticated animals, removed from rigorous natural selection and the timing cues of their natural environment) remain capable of reproduction at all times of the year. Female rats have an estrus cycle of about four days (this means that they are receptive and can mate with a male at four-day intervals, if not already pregnant). A male will mount a receptive female and insert his penis into her vagina, depositing sperm which travel through the uterus to the oviducts where eggs (ova) are fertilized. These fertilized eggs begin to divide and become embedded in the horns of the uterus. Gestation takes about 21 days. Young are born naked with their eyes closed. Parental care includes **nursing**—the provision of milk—by the mother until the young are sufficiently mature to eat solid food. Rats are omnivorous—they eat plant and animal materials, live, dead, or decaying.

Most, if not all, vertebrates prefer certain environmental temperatures. Only birds and mammals, however, are capable of regulating their internal body temperatures within a narrow range. They are said to be **endothermic** (in contrast to **ectothermic** animals, which must to some degree conform to the temperature of the environment in which they live). In mammals, hair aids in reducing heat loss by trapping a shell of air around the body, thus providing an effective insulating blanket. Insulation is also one of the functions of the feathers of birds.

Procedure

1. Examine a preserved rat. Note that the major divisions of the body are the **head, neck, trunk,** and **tail** (Figure 33A-4). The trunk is divided into the **thorax** in the region of the rib cage and the lower or more posterior **abdomen** behind the ribs.

2. Locate the **anus** beneath the tail. Note that most mammals do not have a cloaca—the digestive system opens separately from the urogenital ducts of the excretory and reproductive systems. If your animal is a male, find the large **scrotal sacs** at the base of the tail and the **penis** in front of the anus. If your specimen is a female, locate the **vagina** in front of the anus.

   a. What is the sex of your rat? ______________________

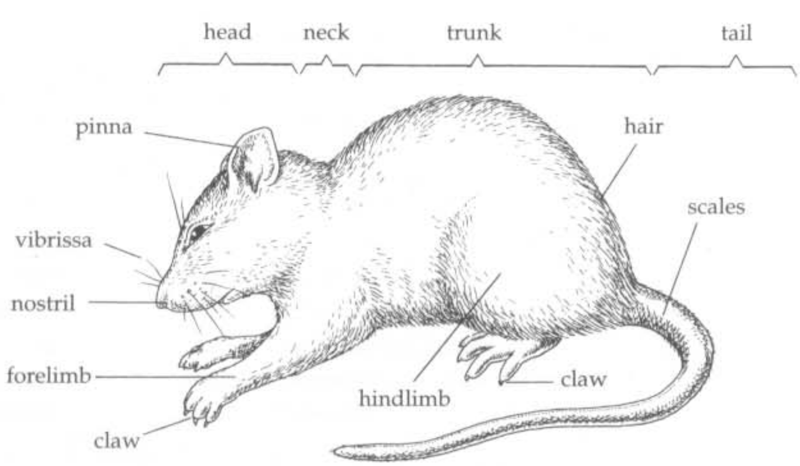
3. Find the paired **external nares** at the tip of the snout. These lead to a series of chambers (including one in which olfactory sensory cells are located) above a **palate,** the roof of the mouth cavity, separating the nasal passageways from the mouth cavity anteriorly. The **internal nares** open into the pharynx behind the mouth cavity. Feel the bony palate.

   b. What might be the advantage of this partitioning of the mouth cavity?

   ____

4. Examine the mouth. Part the lips and examine the teeth. Cut through the angle of the jaw on the left side and open the mouth to see the teeth. Note that the large teeth at the front of the

Figure 33A-4 *External anatomy of the rat.*



mouth, the incisors, are chisel-like and modified for cutting. More posterior teeth are used in grinding. In most submammalian vertebrates, the teeth are all similar or **homodont.** The type of dentition that includes several distinct types of teeth is called **heterodont.** Modifications of mammalian teeth are related to the types of food eaten in each group. The differences in types of teeth and the numbers of each type are distinctive enough to be used to classify mammals.

c. Where are the teeth of the rat located with respect to the margins of the mouth?

____

d. How does the positioning of teeth differ in the rat and the shark? ______________

____

e. Are the teeth located in bony sockets in rats? ______ *In sharks?* ______

5. Examine the eyes. Note that movable upper and lower eyelids are present. Can you find a remnant of the reduced **nictitating membrane** in the inner corner of the eye? The **external ears** are associated with a flap of skin, the **pinna,** which can be moved in different directions to pick up sounds selectively. These sounds travel through the canal of the **outer ear** to the tympanic membrane bounding the **middle ear,** which is recessed. (Where is this membrane in the frog?) A series of three small bones transmits vibrations to the **inner ear.** Note the sensory hairs, called **vibrissae,** on the flexible snout.

6. Study the **forelimbs** and **hindlimbs.** Note the **claws** found on each.

   f. How many digits are on each forelimb? ______ *Hindlimb?* ______

7. Examine the skin on the body and tail. Note the scalelike epidermis of the tail and the relation of these scales to hair. Is there a pattern to their association? (One theory holds that in the

Table 33A-1 Features of Representative Vertebrates

Feature	Shark	Frog	Turtle	Rat
Habitat	Aquatic	Transitional (aquatic larva)	Secondarily aquatic	Terrestrial
Body divisions	Head, trunk, tail	Head, trunk	Head with neck; trunk (in "shell")	Head with neck; trunk, tail
Digestive system	Mouth, cloaca	Mouth, cloaca	Mouth, cloaca	Mouth, anus
Teeth	Homodont	Homodont	Absent	Heterodont, in sockets
Respiratory system	Internal gills	External gills (larva) Lungs, skin (adult)	Lungs	Lungs
Sense organs	External nares Eyes No middle or inner ear	Nares to mouth Eyes Tympanum (middle ear), inner ear	Nares to mouth Eyes Tympanum (middle ear), inner ear	Nares to pharynx Eyes External, middle, and inner ear
Locomotion	Swim (fusiform body)	Jump, swim	Swim, walk	Walk, run
Integument	Placoid scales Unicellular glands	Moist, vascularized Multicellular glands	Horny skin Glands reduced (scent glands)	Hair Sweat and sebaceous glands; mammary glands
Reproduction	Viviparous, internal fertilization (clasper)	Oviparous, external fertilization (amplexus)	Oviparous, internal fertilization (penis)	Viviparous, internal fertilization (penis)

evolution of mammals, hair first appeared as sensory structures associated with epidermal scales. The hair on the tail of rats is too sparse to serve as insulation; instead, it continues to serve a sensory function.)

SUMMARY

Working with your partners, study Table 33A-1. Ask the other members of your group to show you the major features of their organisms and to teach you the important aspects of the reproduction and the life history of those organisms.

We are now ready to begin our study of the organ systems of the four representative vertebrates. We will begin by examining the integumentary system (skin) in this laboratory.

✓ EXERCISE B Integument—A Dynamic Interface

The outer tissue layers of vertebrates form the skin or integument which provides an interface between the internal and external environments. The integument functions in the following ways:

Protection

Mechanical Provides a barrier against abrasion, injury, attack, parasites, pathogens.

Chemical Forms a buffering barrier to passage of water and ions; can also include the production of mucous and other secretions.

Visual Provides pattern or color for camouflage or warning, for attraction and communication.

Light Intercepts ultraviolet radiation and prevents its penetration into deeper layers of the body.

Locomotion Ciliary movement of aquatic larvae; transmission of the physical force required for movement; scales, pads, or claws provide attachment to surfaces.

Respiration Gas exchange between external environment and blood vessels close to the surface in some species.

Secretion Glandular secretions modify the interface with the environment (e.g., a mucous coat "streamlines" certain fishes); may provide mechanical protection or may be toxic; may provide species identification or function as behavioral cues (pheromones).

Excretion Ammonia and simple wastes diffuse across the integument in some vertebrates.

Water uptake Some amphibians can take up water through their skin.

Synthesis Formation of vitamin D (with sunlight).

Heat exchange Heat gain or loss affected by the presence of pigments and by other epidermal structures such as sweat glands, hair, feathers.

Energy storage Fat deposits.

Monitoring the environment Sensors (receptors).

Behavior Effectors include muscles, glands, and pigment cells.

The skin of vertebrates is composed of two layers, the outer **epidermis** and the deeper **dermis.**

EPIDERMIS

The deepest layer of the epidermis, the basal layer, usually consists of a single layer of cells. It is this layer of the epidermis that is most mitotically active; the new cells produced in the basal layer are pushed up through the other layers of the skin to replace cells worn away or shed from the surface.

In many aquatic organisms such as the shark, the epidermis is relatively thin and all of its cells are living (Table 33B-1). In vertebrates that made the transition from water to land, the epidermis is thicker

Table 33B-1 Comparison of the Skins of the Vertebrates Studied in This Laboratory

Trait	Shark	Frog	Turtle	Rat
Epidermis	Living, thin	Dead, thin	Dead, thick	Dead, thick
Specializations	None	Some keratin	Highly keratinized epidermal scales (scutes)	Hair, composed of keratin
Glands	Unicellular mucous glands	Multicellular mucous and granular glands	Few glands	Sebaceous, sweat, and mammary glands
Dermis				
Chromatophores	Present	Present	Present	Present; melanophores invade epidermal structures
Dermal bone	Absent	Reduced, becomes part of skeleton	Redeveloped, as dermal plates of carapace and plastron in association with skeleton	Reduced, becomes part of skeleton
Dermal scales; teeth	Placoid scales; teeth	No dermal scales; small teeth	No dermal scales or teeth	No dermal scales; teeth in sockets

and cells die and become infiltrated with a horny, proteinaceous material, **keratin,** as they move toward the surface (away from sources of nourishment). This process of keratin deposition is called **cornification;** it reduces the permeability of the skin to water and protects the organisms from desiccation. The outer **cornified layer** of the skin of terrestrial animals is composed of dead, cornified cells.

Life on land led to further modification of the epidermis, including specialized, highly keratinized structures such as the **epidermal scales** of reptiles and birds, the **feathers** of birds, and the **hair** of mammals. Feathers and hair trap an insulating layer of air around the body and are important in the evolution of **endothermy** in birds and mammals.

Within the epidermis, glands perform a variety of functions. In aquatic vertebrates, numerous **mucous glands** secrete the viscous mucus that protects the surface of the epidermis and reduces the friction of the body in water. Mucus may also retard the loss of water to the environment. In addition to mucous glands, amphibians also have **granular glands,** which produce a variety of watery secretions—some of them toxic (Indians of the Amazon basin use toxins from amphibians in making their poison arrows). Animals with a fully terrestrial life style generally have fewer epidermal glands—in part, to prevent the loss of water in secretions. Reptiles, for example, have only a few glands, which function in species recognition, reproduction, or defense. In birds, a single oil gland at the base of the tail is used to condition feathers. The major epidermal glands of mammals include sebaceous glands, two types of sweat glands, and mammary glands. **Sebaceous glands** are associated with hair follicles and produce oily secretions (**sebum**) that soften and condition the hair and skin surface. **Eccrine sweat glands,** found in humans and some other mammals, produce watery secretions (sweat) important in evaporative cooling. These glands open onto the surface of the skin between hairs. **Apocrine sweat glands** are associated with hair follicles; in humans, these glands are found in the armpits and pubic region but are not involved in thermoregulation. Apocrine secretions contain cellular debris which, when decomposed by bacteria, produces characteristic odors. **Mammary glands** are specialized integumentary glands found only in mammals; these glands produce milk for the nourishment of young.

DERMIS

The dermis is separated from the epidermis only by a thin basement membrane secreted by the basal layer of the epidermis. The dermis is composed of connective tissue, mainly collagen and elastin fibers in a gel-like matrix. In addition, the dermis contains blood vessels, nerves, sensors, and fat (adipose tissue).

Pigment cells, **chromatophores,** are a conspicuous element of the dermis. In most vertebrates, the most common type of pigment cell is a **melanophore** containing the brown pigment melanin. Some vertebrates also have lipophores containing red, orange, or yellow pigments. Chromatophores are concentrated in the upper layer of the dermis and, in endotherms, portions of these cells sometimes bud off and invade epidermal structures to provide a fixed pigment pattern to feathers and hair. However, in a variety of ectothermic vertebrates, chromatophores are capable of changing their size and shape and thus the pattern of coloration. If all of the melanophores, for example, are contracted so that their pigment (melanin) is highly concentrated in small, widely separated dots, colors and patterns provided by other pigment cells and structures are evident. When the melanin is dispersed to cover a wide area of the skin, however, the color is darkened and other colors and patterns are hidden. These changes may be mediated directly by light, indirectly by endocrine changes, or rapidly through nerve impulses—thus qualifying these cells as effectors (producing an externally directed response), like muscles. Color changes may assist an organism in absorbing radiant energy from the sun, in hiding from enemies, or in communication.

DERMAL BONE: EVOLUTIONARY TRENDS

Normally, we do not think of bone as part of the skin, but in many of the earliest jawless fishes, heavy plates of bone, formed by the direct deposition of calcium salts within the dermis of the skin, provided an external armor. In contrast, bones forming the internal skeleton (the backbone or vertebral column and base of the skull) first developed as cartilage which was replaced from within by bone during maturation. Thus, two types of bone were found in early vertebrates: **dermal bone** formed in the skin and **endochondral,** or **replacement, bone** formed by the replacement of cartilage to provide an endoskeleton.

In the earliest jawed fishes, the dermis produced **dermal scales** composed of layers of dermal bone overlaid by a layer of dentine-like material (also derived from the dermis) and an enamel-like layer applied to the surface, possibly by the epidermis. As fish evolved, several of these layers became modified or reduced. In sharks, dermal bone is largely absent and only the outer layers of dentine and enamel persist in the placoid scales. The scales of bony fishes are thin disks of bone that develop in overlapping dermal folds of the skin. In bony fishes, dermal bone also becomes incorporated into the skeleton as part of the skull and the pectoral girdle—the only remnants of dermal bone that persist in terrestrial animals. There are some exceptions, however; for example, in turtles, dermal bone forms part of the carapace (shell) and also becomes part of the skeleton.

As you examine the four representative vertebrates being studied by your group, be sure to notice the following adaptive trends associated with the phylogenetic spectrum from jawless fishes to endotherms: (1) a general reduction in the importance of bony elements of the dermis and (2) a corresponding increase in the diversity and importance of epidermal structures (Table 33B-1).

Objectives

- ☐ Describe the functions of skin.
- ☐ Trace the development of dermal and epidermal structures in the integument in the four representative vertebrates.
- ☐ Explain the adaptive roles of epidermal and dermal structures.

Procedure

Shark

1. If available, study a prepared whole-mount slide of shark skin using the 10× objective of your microscope. Alternatively, use a scalpel to make a small incision through the skin of your shark. Lift one edge of the cut and separate a small section of skin from the underlying muscle. Mount this skin on a microscope slide for study. (Scales can be seen more easily if the skin is soaked overnight in glycerine and then mounted—your instructor may provide material for you to study.)

2. Recall that the shark's epidermis is made up entirely of living cells with few specializations.
   a. *How is the shark's skin different from that in the other organisms being studied?*

   b. *Where do new epidermal cells originate?*

   Gland cells are present and produce mucus, but sharks do not develop a "mucous cuticle," a streamlining cover found over the epidermis in some other aquatic vertebrates.
3. The dark color of the skin of sharks is due to pigment cells, **melanophores,** containing a dark brown-black pigment, melanin. Can you find the melanophores?
4. Note the regularly spaced dermal scales, often called denticles or "little teeth" because their structure resembles that of a tooth. These are the **placoid scales** (Figure 33B-1).
5. If available, examine the slide of fish skin using the 10× objective.
   c. *Describe the origin of the scales and the relationship of the scales to the dermis and the epidermis.*

   d. *How do the scales of other fishes differ from the placoid scales of the shark?*

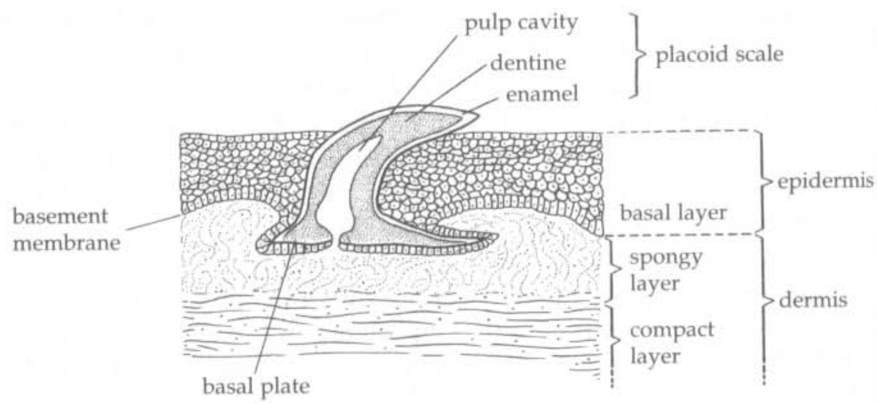
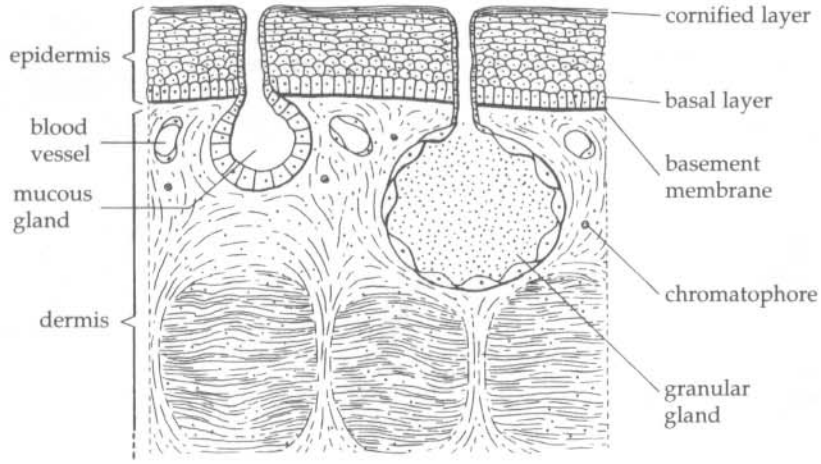


Figure 33B-1 *The integument of sharks. Cross section through the skin and placoid scales. Cells within the epidermis form an enamel organ which induces a thickening in the underlying dermis. Each scale has an inner dentine layer, produced by mesenchymal cells of the dermis, and an outer enamel layer. The origin of the enamel is unclear, but possibly is secreted by epidermal cells. Placoid scales develop similarly to the teeth of higher vertebrates; the enamel contains the same proteins found in mammalian teeth.*

Frog

1. Obtain a prepared slide of a cross section through the skin of an adult frog or other amphibian. Study it under the 10× objective of your microscope. Identify the epidermis and the basal layer. In contrast to the epidermis of the shark, the outer layers of cells in the frog's epidermis are dead and provide a protective covering. The frog's epidermis is generally only five to eight cells thick (Figure 33B-2).
   a. *Describe the process of keratinization in the formation of the outer cornified layer of the epidermis.*

Figure 33B-2 *Section of the skin of a frog.*



2. Study the dermis in the prepared slide of frog skin. Identify the multicellular **mucous glands** and large **granular glands,** both epidermal structures that have grown into the dermis. (Curiously, in the Surinam toad, granular glands produce secretions that nourish developing tadpoles held in skin pockets on the backs of females.)

   b. What are the functions of mucous glands in most adult amphibians?

   ____

   Of granular glands? ______________________________

3. The dermis also contains muscles, pigment cells, blood vessels, nerves and nerve endings, a variety of connective tissue cells and fibers, and other structures. Do you find any trace of dermal scales? (Remnants of dermal scales are present in some amphibians such as caecilians and a few anurans.)

Because the skin of the adult frog is thin and richly supplied with capillaries, oxygen can diffuse through the body surface and into the blood supply. Thus a frog's skin serves as an accessory respiratory organ. (In the evolution of one line of salamanders, the plethodonts, lungs have been lost and all gas exchange must occur across the skin and the lining of the mouth cavity.) On the other hand, thin amphibian skin does little to protect the occupant from desiccation, and adult amphibians are generally restricted to humid environments. Some remain aquatic.

c. In what parts of the world would you expect to find the greatest amphibian diversity?

____

Turtle

1. Recall that the large keratinized epidermal scales (**scutes**) that make up the outer covering of the carapace and plastron of the turtle are derived from the epidermis. Now observe the skin on the legs of the turtle.

   a. How do the epidermal scales on the appendages differ from those covering the carapace?

   ____

   b. How does the epidermis of the turtle differ from that of the frog? ____________________

   ____

Increased keratinization of the epidermis in reptiles markedly retards water loss from the body and is a major factor in the adaptation of reptiles, birds, and mammals to land. In reptiles, the epidermis is

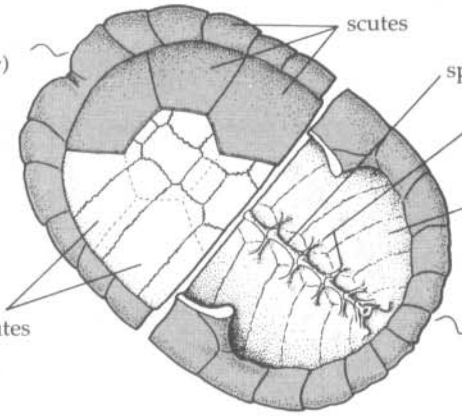


Figure 33B-3 *A turtle skeleton showing elements of the axial and dermal skeletons forming the carapace.*

generally thin and consists, as in amphibians, of a basal layer where cells multiply and successive layers where keratin is added. However, the outer layer of dead cells, the **cornified layer**, is much thicker and is less permeable to water than the outer layer of the skin in frogs. In reptiles this layer may be shed (molted) regularly (as in snakes and lizards) or retained as growth occurs (as in most turtles and alligators), giving the skin its characteristic "scaly" texture. The retention of the cornified layers results in a gradual increase in scute thickness and this may be used to estimate age in some turtles. Recall that terrestrial vertebrates have lost most of their skin glands in the course of evolution.

c. Why has the move from an aquatic to a terrestrial environment caused a reduction in the number of skin glands?

____

____

The epidermal scutes and underlying plates of dermal bone that form the carapace and plastron of the turtle both develop from the skin. Thus, the "shell" of the turtle is really a part of its skin; it is continuous with the skin covering the head, tail, and appendages. (Contrary to the animated liberties taken by cartoonists, turtles cannot leave their shells!) Dorsally, the dermal elements of the carapace fuse with the endochondral bone of the vertebral column and ribs of the endoskeleton.

2. Study the skeleton on demonstration to identify the bony dermal elements of the carapace and plastron (Figure 33B-3).

d. Do the shapes and locations of dermal bones forming the carapace match the edges of the epidermal scutes seen on your specimen? ______

e. How are the development and structure of the bony dermal elements in the turtle different from the development and structure of scales in fish? ______________________

____

____

As in sharks and frogs, **chromatophores** (pigment cells) are found in the turtle's dermis, where they produce the specific patterns and colors of the skin.

Rat

1. Observe a cross section of human skin (or other mammalian skin) using the 10× objective of your microscope. The outer epidermis is thick and cornified to reduce water loss, but does not form the keratinized scales present in reptiles.

Several epidermal specializations are found in mammals. Epidermal hairs, growing down into the dermis, are associated with smooth muscles that can change the orientation of the hair shaft, thus

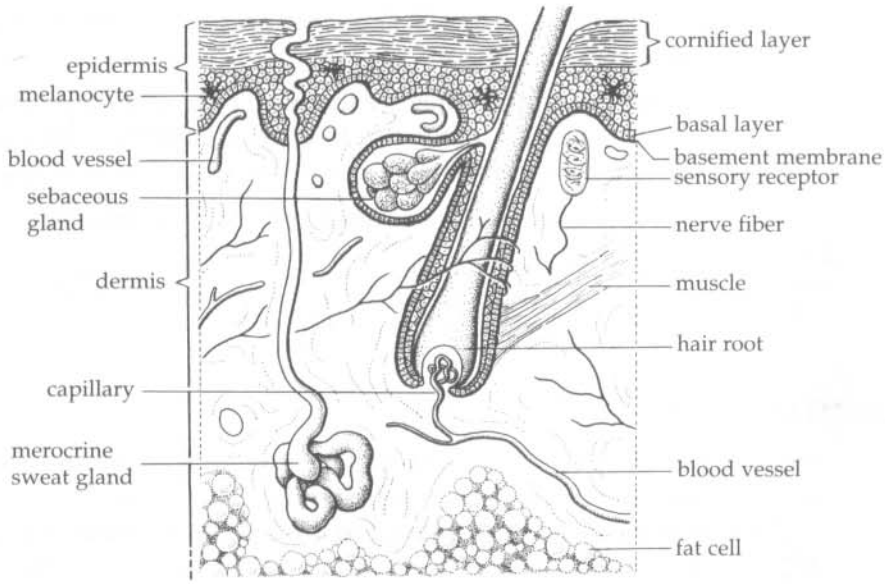


Figure 33B-4 *Schematic drawing of a section of human skin. The integument of the rat is similar, but contains more hair follicles and lacks eccrine sweat glands. Apocrine sweat glands, not involved in evaporative cooling of the warm body surface, are associated with hair follicles in rats and are found in the axillary and pubic regions of humans.*

changing the thickness of the layer of air trapped by the coat of hair. (In humans, "goose bumps" are a remnant of this thermoregulatory response—ineffectual because during the course of evolution we have become much less hairy than our ancestors.)

2. Epidermal glands are another specialization. Refer to Figure 33B-4 and identify the **sebaceous glands.**

   a. What is the function of sebaceous glands? ______________________________

   ____

3. If you are examining a cross section of human skin, locate a **eccrine sweat gland** (Figure 33B-4).

   b. What is the function of the eccrine sweat glands? ______________________________

   ____

   Recall that these glands are not found in rats. In rats, cooling is accomplished by evaporation of water from the mouth and respiratory tract. Urine may also be used to moisten the fur and legs to facilitate heat loss.

4. Find the external openings, the **nipples,** of the mammary glands of your rat. These specialized integumentary glands are found along each side of the body.

   c. How many nipples are there on your rat? ______ *Why do you suppose rats have more nipples than humans?* ______________________________

   ____

Other keratinized, epidermal structures of mammals include the **horns** of cattle (but not the antlers of deer, which have a bony core covered with skin), **baleen** of some whales (plates in the mouth cavity that filter food—tiny plankton—from the water), horny **scales** (in the pangolin and armadillo), and **nails, claws,** and **hooves.**

The dermis of mammals contains connective tissue cells and fibers; muscles, nerves and sensors; blood vessels and capillaries; glands and hair follicles extending down from the epidermis; and, toward its base, a layer of fat cells that becomes quite thick in aquatic mammals such as seals and whales. In water, it is difficult for hair to retain a trapped layer of air to reduce heat loss, so, in the most advanced mammalian aquatic organisms, the coat of hair has been reduced and thick layers of fatty tissue have been substituted as an insulating layer.

5. Study your slide. Identify the epidermal hair follicles and glands that invade the dermis. Locate muscles that attach to the hair follicles. Find connective tissue elements. Examine the innermost layers of dermis on your slide. Can you find fat cells?

   d. Why is fat tissue generally a less efficient thermal insulator than hair? (Hint: Which tissue is living and vascularized?) ______________________________

   ____

SUMMARY

Review Table 33B-1 on page 33-14. Be sure you understand the phylogenetic trends in the integument of the representative vertebrates dissected in this laboratory.

Recall that the vertebrates studied in this lab show several specializations overlying general phylogenetic trends. Thus, dermal bone has been lost almost completely in the shark, but some other fishes retain some bone in their scales; it also reappears in the turtle. Nevertheless, the trend is toward restriction of dermal bone to specific sites—the skull and pectoral girdle—in the phylogenetic transition from aquatic to terrestrial organisms.

a. What phylogenetic trends are illustrated by epidermal structures in your representative vertebrates?

____

____

____

Laboratory Review Questions and Problems

1. Use anatomical terms for position or direction to describe the locations of the following vertebrate organs:

   Mouth

   Toes of a pig (in relation to the limb)

   Toes of a human (in relation to the limb)

   Tail

2. List the organ systems of vertebrates. Given an example of at least one organ contained in each.

3. Compare and contrast integumentary structures in the shark, frog, turtle, and rat. What are the characteristics of the skin in each animal?

What are the major similarities of the skin in these animals?

What are the major differences in the skin of these animals?

4. How do the different structures in the skin of the four vertebrates studies in this lab adapt each animal to its major environmental factors?

Shark

Frog

Turtle

Rat

5. Why is it advantageous to terrestrial vertebrates to have a nonliving outer layer of epidermis in contact with the environment?

6. Birds and mammals use feathers and hair, respectively, to trap an insulating layer of air around the body, retarding heat loss and assisting in the maintenance of a relatively constant internal body temperature (endothermy). In other living vertebrates, body temperature is ultimately dependent upon that of the environment (ectothermy). What are the advantages of endothermy? Of ectothermy? What are the disadvantages of endothermy? Of ectothermy? How would these advantages and disadvantages be modified in animals of increasing or decreasing body size (mass)?

COMPARATIVE ANATOMY AND CONCEPTS OF VERTEBRATE EVOLUTION

Now that you have been introduced to the series of dissections of the four representative vertebrates, you should keep in mind that studies such as the one you are undertaking introduce many terms with which you may be unfamiliar. You are NOT expected to memorize these terms. Rather, they provide a "vocabulary" that enables you to locate various structures by using both written descriptions and diagrams. If you wish to develop your understanding of the vocabulary of biology, Appendix V—Key to Common Roots, Prefixes, and Suffixes—at the end of the laboratory manual will help you to understand the meanings of biological terms and relationships among terms. As you study the vertebrates, focus on the following concepts of vertebrate evolution rather than on details.

- Dermal structures become reduced and epidermal structures diversify.
- Major sensors remain similar in structure but, with the transition from water to land, the lateral line system for "distant-touch" disappears and some of the structures of the pharynx become modified for hearing.
- The forebrain increases in size and importance; in mammals, both optic and auditory sensory information are projected to the forebrain rather than to the midbrain.
- Muscles and bones work together to produce movement which becomes more complex with the development of limbs.
- The coelom becomes partitioned to separate the heart and lungs from the general body cavity.
- The digestive system is modified to accommodate increasing complexity in diet.
- Swim bladders and lungs replace gills as the major respiratory organs, facilitating the transition to land.
- The heart is modified to separate pulmonary circulation from general body circulation in terrestrial vertebrates.
- Posterior elements of the kidney become increasingly important in urine formation, and anterior elements become associated with the male reproductive system.
- Developing young tend to be retained within the mother or within an enclosed egg.