

## Biology 3B Laboratory

### Comparative Anatomy of the Vertebrate Skeletal Systems

#### OBJECTIVES

- To identify certain bones that comprise the skull of various vertebrates
- To compare the differences size, shape and occurrence of cranial bones in various vertebrates
- To identify the bones that comprise the post-cranial skeleton of various vertebrates
- To compare the postcranial skeletons of a variety of vertebrates, noting differences in size and other factors that affect the types of locomotion that the skeletal system supports



#### Warnings:

- Avoid touching skulls with **PEN or PENCIL TIPS!**
  - Use a blunt probe or dissecting probe.
  - Anyone found using a pen or pencil on bones will lose 10 points!
- Small skulls are very fragile, **HANDLE WITH CARE.**
  - If a skull was found in a box, return it to the correct box.
  - Do NOT pile skulls or jaws on top of each other (unless they fit together).
  - Do NOT balance a skull on top of a box that is too small for that skull.
- Absence of a bone or structure in your list may mean that the bone or structure is:
  - absent from that taxon OR too small to find easily OR not ossified in that species

#### INTRODUCTION

This laboratory is to introduce you to the skeletal systems of various vertebrates. As you examine the skeletal features for each group, you will associate their particular structure with the following types of locomotion: **cursorial** (very fast running), **fossorial** (digging), flight, swimming and movement without limbs. In this exercise you will examine representatives of the major vertebrate classes to discover some trends in the evolution of the skeletal system. Special attention will be paid to changes that have occurred in skull and skeletal structures.

Examine each of the following skulls and skeletons, pay attention to the relative complexity, strength and thickness of the components. **Handle all specimens with care. They are all fragile and expensive to replace.**

Based on the embryonic origin of the bone, the skeleton of vertebrates is divided into two main portions. The **integumentary skeleton** has its origin as dermal bone (bony scales, teeth, and superficial bony plates develop in this manner). The **endoskeleton**, on the other hand, develops within the body wall and can be further divided into axial, appendicular and visceral portions. The **axial skeleton** includes the skull, vertebral column, ribs, and sternum while the **appendicular skeleton** is composed of the appendages and their supporting girdles. The third portion of the endoskeleton, the **visceral skeleton**, develops in association with the pharyngeal gill slits.

#### COMPARATIVE SKELETAL ANATOMY

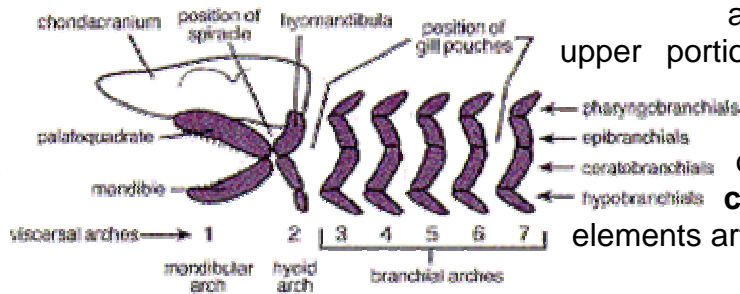
The bones of the vertebrate skull are one of two types: endochondral or dermal. **Endochondral bone** or cartilage replacement bones are preformed in the embryo as pieces of cartilage with each

transformed into one or more individual bones in the adult. **Dermal bones** evolved originally from scales and formed directly as bone in membranes (a.k.a. membrane bone).

The “primitive” condition of a skull essentially consists of two “boxes”, one located inside the other. The inner box is the **neurocranium** (brain case) consisting of endochondral bones; and the outer box is largely dermal bone. The unossified neurocranium in either the embryo or adult is known as the **chondrocranium** (i.e. Chondrichthyes) and functions in supporting the brain and sense organs. A general evolutionary trend in the vertebrate skull is the reduction of the top and sides of the neurocranium box and the incorporation of dermal bones into these areas. This trend results in the single box of both dermal elements (top and sides) and endochondral elements (bottom and back), which we see makes up the skull of amniotes.

The visceral skeleton consists of all the gill arches and their evolutionary and embryonic derivatives. Each gill arch consists of a set of paired endochondral elements. The **epibranchial** is the upper element and the **ceratobranchial** is the lower element (Figure 1). Primitively all of these elements have dermal teeth bearing bony elements associated with them on the inside. When you examine the perch, you will be able to see the **gill rakers**, used for “chewing”, on the inside of the gill bars. The gill rakers are homologous to the **tooth plates** that you will examine on the roof of the mouth of the dried *Amia* skull. To see the endochondral elements, you will examine the shark skull and full skeletal specimens in the various jars.

Figure 1: Lateral view of chondrocranium.



Jaws were an early step in the evolution of the vertebrates which developed from the anterior gill arches, called the **mandibular arch**. The original upper portion of the jaw consists of the **palatoquadrate cartilage**. You will see this large tooth bearing cartilage in the shark. The original lower portion of the jaw is also a single element, **mandibular cartilage** (or **Meckel’s cartilage**). These two elements articulate at their posterior ends to form the jaw joint.

A second step was the modification of the second visceral arch, the **hyoid arch**. This is a supporting structure for the back of the jaws where the upper and lower jaw elements articulate (the jaw joint). It is the upper portion of the hyoid arch that forms the **hyomandibular** which supports the jaw. Behind the hyoid arch are the remaining **five branchial arches**, each with an upper epibranchial and lower ceratobranchial cartilage.

The palatoquadrate in bony vertebrates becomes ossified and separated into two bones. The anterior bone is **epipterygoid** and the posterior bone is the **quadrate**. In tetrapods (four-legged animals), these bones become incorporated into the base of the neurocranium. The quadrate forms the articular surface with the lower jaw except mammals. The actual functional jaw of most bony vertebrates is the **pre-maxilla** and **maxilla**. In fish, these two dermal bones are moveable whereas in tetrapods, they are firmly and immovably joined to the neurocranium.

In the original (primitive) lower jaw, Meckel’s cartilage can be found in all jawed vertebrates. In bony vertebrates, the Meckel’s cartilage becomes mostly ossified into the main, functional, teeth bearing **dentary bone**. The dermal teeth on the dentary bone operate against the teeth on the premaxilla and maxilla in most bony vertebrates. The posterior portion of Meckel’s cartilage is ossified, forming the **articular**, which articulates with the quadrate. This jaw joint becomes the **quadrate-articular jaw joint**; however, it still retains the original jaw joint described above between the palatoquadrate and Meckel’s cartilage.

In mammals, there is a different jaw joint that is present. The dentary bone forms the entire lower jaw as it has expanded posteriorly and taken over the role of the articular in the jaw joint. The **squamosal** portion of the **temporal bone** forms the side of the skull and takes over the role of the quadrate in the jaw joint. In mammals, the quadrate and articular becomes important bones of the middle ear, the **incus** and **malleus** respectively. The third bone of the middle ear evolves from the hyomandibular, which supported the primitive jaw joint. Since the original upper jaw was incorporated into the floor of the neurocranium, the supporting role of the hyomandibular became unnecessary. The hyomandibular became the first middle ear bone to take up a hearing role. In amphibians and reptiles, the hyomandibular is called the **columella** whereas in mammals, it is the **stapes**.

In mammals, the stapes is positioned between the inner ear and the incus (formerly the quadrate) which in turn articulates with the malleus (formerly the articular). Thus the articulations of these bones in the mammals retain their original articulations from the bony conditions found in bony fish. The comparisons above are depicted in Table 1. Blanks in the table indicate either no homologue or that you are not responsible for them. Bones listed across the same line are homologous.

Table 1: Homologous comparison of the vertebrate skull

<b>Chondrichthyes (dogfish)</b>	<b>Actinopterygii (Perch)</b>	<b>Reptile (Snapping Turtle)</b>	<b>Mammal (Cat)</b>
<b>Skull – Chondrocranium (endochondral from embryonic mesoderm)</b>			
Chondrocranium		Exoccipital	Occipital
		Basioccipital	
		Supraoccipital	
		Prootic	Temporal (mastoid process + bone encasing inner ear)
		Opisthotic	
		--	Presphenoid & Orbitosphenoid
<b>Skull – Visceral Arches (endochondral bone formed from neural crest cells from neuroectoderm)</b>			
Palatoquadrate	Quadrate	Quadrate	Incus
		Epipterygoid	Alisphenoid
Hyomandibular cartilage	Hyomandibular	Columella	Stapes
<b>Skull – Dermal Bones from dermal or membrane bone from embryonic mesoderm</b>			
		Squamosal	Temporal (squamosal portion [jaw joint] + zygomatic portion)
<b>Lower Jaw – Visceral Arches (endochondral bone from neural crest cells)</b>			
Meckel's Cartilage	Meckel's cartilage	Meckel's cartilage	Meckel's cartilage
	Articular	Articular	Malleus
<b>Lower Jaw – Dermal Bone (dermal bone)</b>			
		Angular	Temporal (Tympanic portion)

**Specimen Examination:**

- You are responsible for locating and being able to identify the structures that are in bold.

➤ **Shark (Dogfish – *Squalus*):** Examine the shark skeletal structures. The chondrocranium is composed of unossified cartilage and, like all vertebrate skulls, includes components from both the integumentary skeleton and endoskeleton. The **chondrocranium** almost completely encircles the brain has an endoskeletal origin (the upper roof of the brain case is of dermal origin; Fig 2). The anterior portions of the brain are protected by a cylindrical extension of the chondrocranium (the **rostrum**). Posterior to the rostrum **nasal capsules** house the olfactory apparatus and are tied together by the **ethmoid plate**. Toward the dorsal surface and behind the nasal capsules, depressions in the chondrocranium create shallow eye sockets (the **orbital plates**; not visible in the ventral view of Fig 2). **Otic capsules** surround those parts of the ear that lie within the brain case (locate these swellings at the posterior of the chondrocranium). The spinal cord exits the braincase at the **foramen magnum** and the bulbous **occipital condyles** (near the foramen magnum) articulate with the first vertebrae. Locate the **visceral arches** near the rear of the chondrocranium. Ancestral vertebrates were filter feeders and jaws probably evolved to allow ingestion of larger food scraps. Although dermal bones contribute to the formation of the jaws in other vertebrates, those of cartilaginous fish are built entirely from the first visceral arch. Locate the **palatoquadrate** which is formed from the epibranchial portion and **mandibular (Meckel's) cartilage** formed from the ceratohyal, both bearing teeth. The palatoquadrate has a pair of thin "tentacle like" labial cartilage extending anteriorly. See if you can locate the **hyomandibular** articulation at the jaw joint. The **ceratohyal** comprises the lower portions of the visceral arches. Find the **epibranchial** portion of the visceral arch. Locate the remaining **branchial arches**. The other portions of the arch support the gills and pharynx.

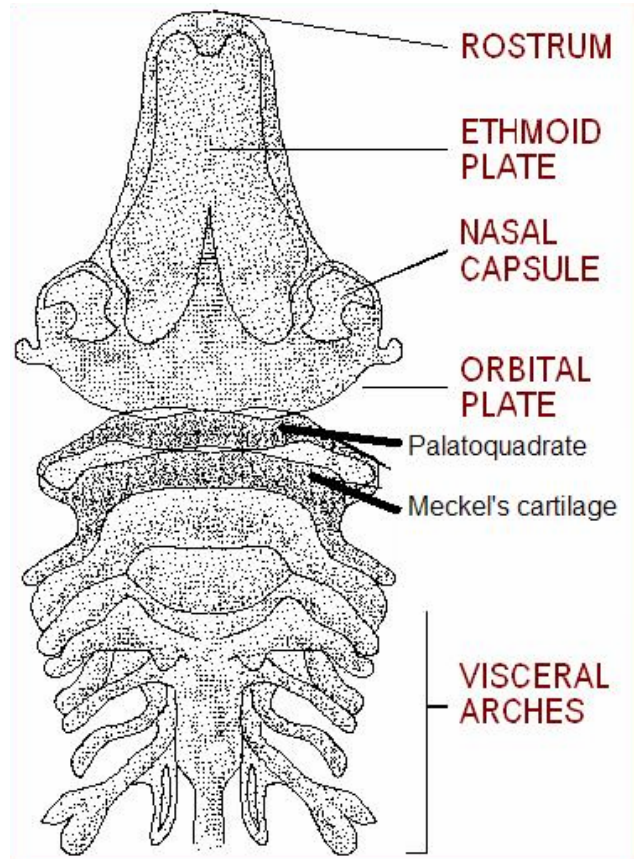
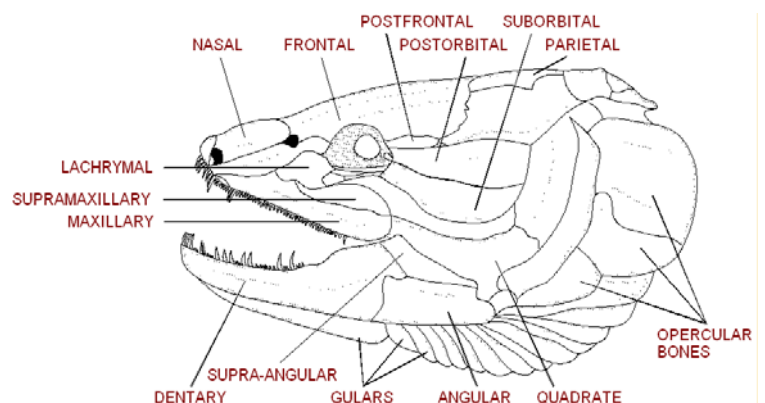


Figure 2: Chondrocranium with visceral arches (ventral view).

- On the dogfish skeleton, observe the position of the pectoral and pelvic girdles and fins. The dogfish's caudal fin is **heterocercal tail** (the dorsal lobe is enlarged compared to the ventral lobe).

➤ **Bony Fish (*Amia*).** The chondrocranium of a primitive bony fish (such as the bowfin, *Amia*) is completely covered by fused plates of dermal origin (collectively called the **dermatocranium**; Fig 3). Note the thickness of these bones. How many bones surround the eye socket (**orbit**) of your specimen? Describe the general shape of the teeth (are they similar to one another?). Recall that the dermal teeth are homologous to gill rakers (you will see these in the perch).

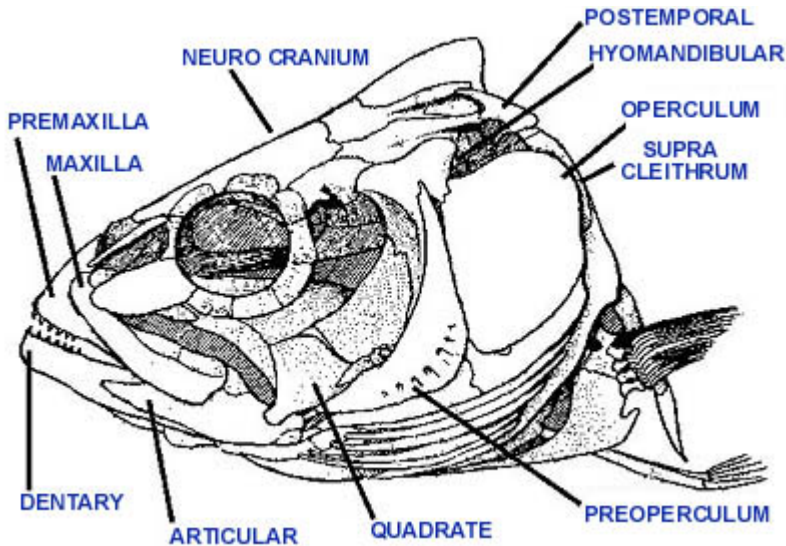
Figure 3: *Amia* skull



- Examine the skull of *Amia* and locate the following bones: **nasal, frontal, postorbital, parietal, maxillary, dentary, angular, quadrate and operculum**. To find the **hyomandibular**, you will need to look inside the gill chamber as it is hidden by lateral view.

- **Bony Fish (Perch – *Perca*)**. Examine the skull of a perch. The first thing that you should notice in the perch skull is a reduction in the number of bones compared to the bowfin skull. A hinge separates the premaxilla and maxilla of the bowfin, whereas the same two bones in the perch are moveable. Using Figure 4 (below) locate the following bones on the skull: **nasal, frontal, parietal, pre-maxilla, maxilla, dentary, articular, quadrate, hyomandibular** (supports the operculum) and **operculum**.

Figure 4: Perch skull.



- Using the fish skeleton, find the following structures on the vertebral column (strong front to back because of the pressure from moving through the water, however, the vertebra are relatively weak with dorsal/ventral pressure): **neural spine** comes off of the **neural arch** (protects the spinal cord). The neural arch is fused to the centrum of the vertebrae where the **epipleural (dorsal) ribs** come off (these are pointing straight at you) and the **pleural (ventral) ribs** that come down and protect the visceral organs. The pleural ribs are homologous with our ribs. In the posterior portion of the fish, the

**dorsal aorta** is protected by the **haemal arch** located below the centrum. The **haemal spine** comes off of the haemal arch.

- Locate the two dorsal fin rays: the anterior bony **actinotrichia** and the posterior keratinized (softer) **lepidotrichia**. Located ventral to and supporting the dorsal fins are the **pterygiophores**. The perch's caudal fin is **homocercal** (both lobes are the same size).
- Examine the **pectoral and pelvic girdles and fins**. Notice where the pectoral and pelvic girdles are attached to the perch. Compare the pelvic fin placement of several teleost fishes in the lab. Notice that their placement position varies from the thoracic to the abdomen.

- **Amphibians (mud puppy – *Necturus*)**: This amphibian in its adult form retains some larval characteristics (neotenic); however it still retains some primitive skull characteristics of its ancestors. There is a reduction in the number of bones, an evolutionary trend, in the skull of *Necturus*. The chondrocranium only consists of three bones (exoccipital, opisthotic and prootic). The remaining bones in the skull are dermal in origin. The **quadrate** is the only visceral arch that is remaining.

- Examine the skull of *Necturus* and locate the following bones: **quadrate, squamosal, premaxilla** and **frontal**. On the lower jaw, locate the **dentary** and **angular**.
- Examine the vertebral column of *Necturus*. Notice that the vertebral column is very different than fishes. In order to support the organism on land, the vertebral column becomes more ossified and differentiated into the **cervical, trunk, sacral** and **caudal vertebrae**. The zygapophyses on each vertebra provide increased support and allow for lateral torque but

oppose vertical torque during locomotion. On each vertebra, there is a prezygapophysis and a postzygapophysis.

The **postzygapophysis** on the anterior vertebra overlap with the **prezygapophysis** on the posterior vertebra. The cervical vertebrae allowed for increased head movement. The trunk vertebrae have the short primitive ribs. The sacral vertebrae become fused to increase support for locomotion on land. The caudal vertebrae have the haemal arches as seen in the perch.

- The primitive tetrapod limb structure can be seen in *Necturus*. Since they are neotenic, there is not a bony connection between the **pectoral and pelvic girdles** with the vertebral column. However, other caudates do have the bony connection. On the forelimb you should be able to see the following: **humerus** (parallel to the ground) **radius** and **ulna** ((vertical to the ground)). On the hindlimb, you should be able to see the **femur** (parallel to the ground), **tibia** and **fibula** (vertical to the ground). Notice how the girdles and limbs are more sprawled.

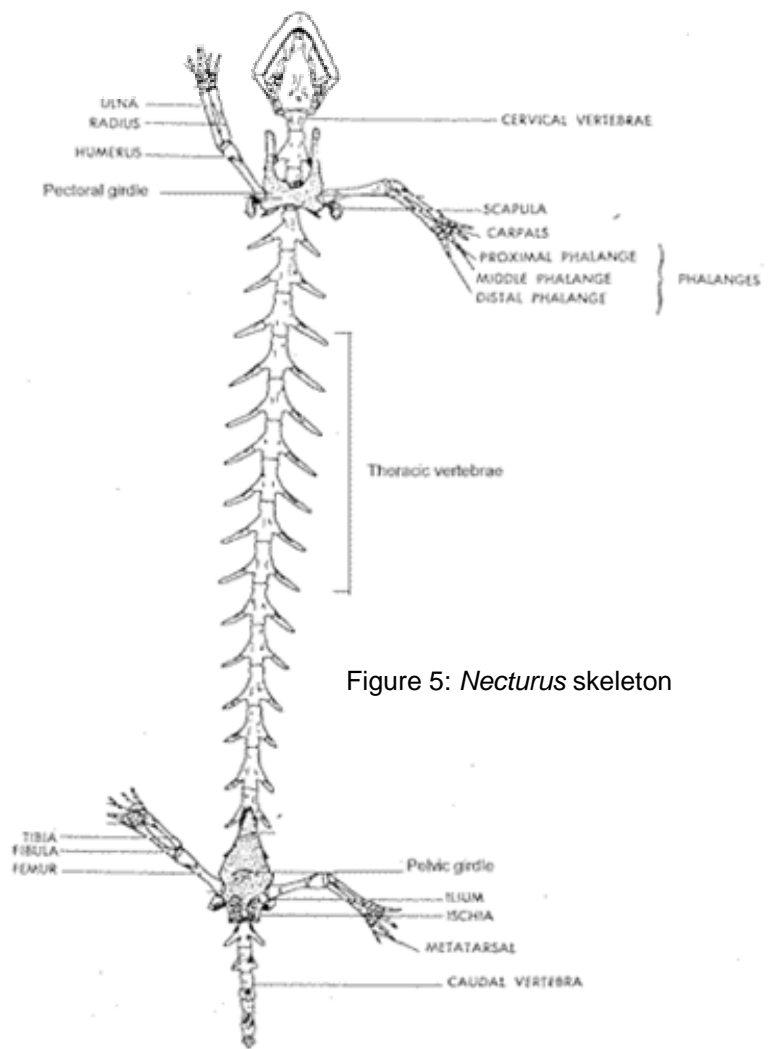


Figure 5: *Necturus* skeleton

➤ **Amphibians (frog – *Rana catesbiena*).** The head skeleton of early amphibians was nearly identical to that of bony fishes but this arrangement has not persisted among contemporary amphibians. Use figures 6 as a guide to identify the major bones of the frog skull. Note that the dermal bones are reduced in number and most of the skull is cartilaginous. The open structure of the skull better accommodates the more elaborate sensory and feeding apparatus of amphibians. Notice the small braincase. Part of the visceral arches has evolved into the **hyoid apparatus**, a structure that supports the base of the tongue (the U-shaped cartilage mounted below the head of your specimen). How does the complexity and strength of the frog skull compare to that of a bony fish?

- Examine the bullfrog skull and locate the following bones: **premaxilla, maxilla, nasal, frontal-parietal, pterygoid, squamosal, quadratojugal, dentary, and vomer.**
- Examine the vertebral column and located the **9 vertebrae.** The first vertebra is the **atlas**, which supports the skull. The **9<sup>th</sup> vertebra** is the **sacral vertebra** which its transverse process articulates with the ilia. The fused caudal vertebra is called the **urostyle.**
- Examine the bullfrog skeleton notice the placement of the pectoral and pelvic girdles.

- Locate the bones of the pectoral girdle (**suprascapula**, **scapula** (located below the suprascapula), **clavicle**, **coracoid**) and the forelimb (**humerus**, **radioulna** (forearm bones are fused), **carpals**, **metacarpals** and **phalanges**).
- Locate the following bones of the pelvic girdle (**ilium** (these are long and articulate with the sacral vertebra), anterior **pubis**, posterior **ischium**) and the hindlimb (**femur**, **tibiofibula**, and the **tarsals**).

Figure 5: Frog skeleton and skull.

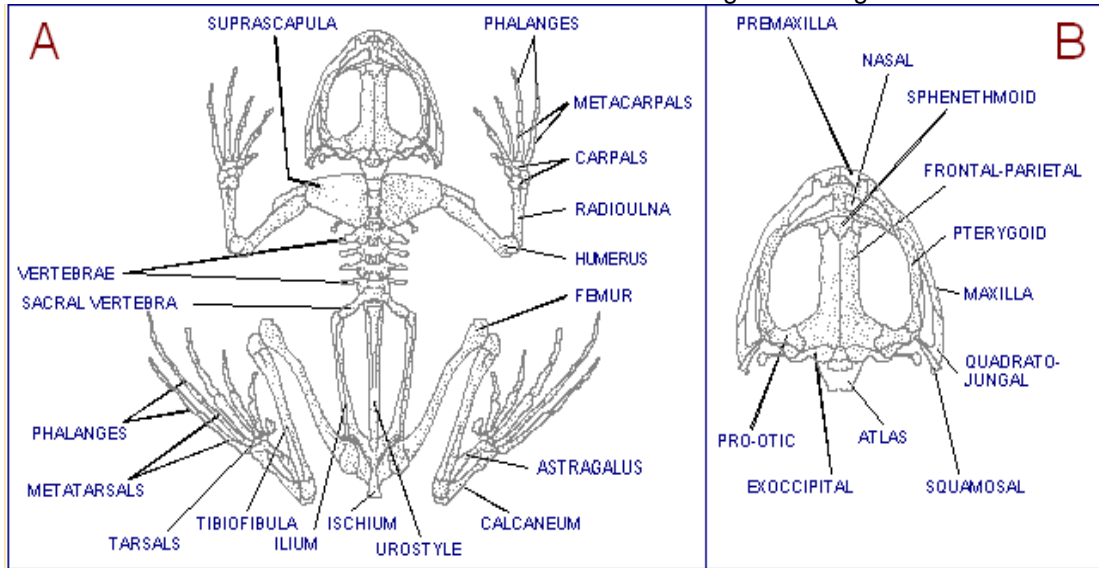


Figure 6: Frog skull and skeleton.

### ➤ Reptiles (Testudines – Sea Turtle & Snapping Turtle)

The turtle represents the **anapsid skull**. The brain is enclosed by several bones including the **frontal** and **parietal**. There is further thickening of the components, greater ossification and a reduction in the number of bones compared to the prior groups. These changes permit better muscle attachments to the jaw and increase the strength of the skull.

- Examine the sea turtle skull and locate the following bones: **premaxilla**, **prefrontal**, **frontal**, **postorbital**, **parietal**, **squamosal**, **supraoccipital**, **quadratojugal** and **quadrate**. Locate the **columella** inside the tympanic cavity. Remember that the columella was the hyomandibular in the perch and dogfish.
- Examine the back of the sea turtle skull and locate the following bones: **exoccipital**, **basioccipital**, **supraoccipital**, **opisthotic** and **prootic**.
- Examine the lower jaw of the sea turtle and locate the three dermal bones: **dentary** (anterior portion) **angular** (posterior & medial) and **surangular** (posterior & lateral) and one endochondral bone, the **articular** (posterior between the angular & surangular).
- Examine the snapping turtle skull and locate the following bones: **premaxilla**, **prefrontal**, **frontal**, **postorbital**, **parietal**, **squamosal**, **supraoccipital**, **quadratojugal** and **quadrate**.
- Examine the tortoise shell. The **plastron** is the ventral portion of the shell and is formed from a single layer of dermal bone. The three most anterior elements are the flattened **clavicles** and **interclavicle**. The dorsal **carapace** is composed of externally flat dermal bones which may bear impressions of the cornified epidermal scutes. Examine the underlying trunk vertebrae on the inside of the carapace which are fused to the carapace as are the flat expanded **ribs**.
- Examine the underlying pectoral and pelvic girdles of the turtle with the plastron that has been cut away. The **scapula** articulates with the first trunk vertebra. The ventral **acromion process** projects anteromedially from the scapula. Lying at a right angle to the scapula, the

ventral **coracoid** projects posteromedially. The pelvic girdle has the dorsal **ilium** that joins broadly with the sacral vertebrae. The **pubis** is anterior and the **ischium** is posterior.

- Examine the four limbs of the turtle. Notice that all the limbs are relatively short and stout to support the heavy body. Located the **femur, tibia, fibula, tarsals, humerus, radius, ulna** and **carpals**.

### ➤ Reptiles (Lepidosauria – Squamata – Serpentes – snakes)

The skulls of snakes are highly unique. The braincase is highly ossified; the bones of the roof of the cranium grow downwards on either side of the brain to enclose it completely in a bony capsule. This prevents the brain being damaged by struggling prey. The rest of the bones in the skull are connected by elastic ligaments and are able to move sideways and backwards at any time referred to as cranial kinesis. It is the jaws that are the most interesting aspect of the snake skull. It is the snake head that is responsible for both prey capture and prey transport and it is the jaws that accomplish both functions.

The joint between the upper and lower jaw is positioned well back in the skull and this allows snakes to open the jaw as wide as possible. The bones of the upper jaw are not united at the snout, but are free to move away from one another. This increases the opening of the mouth and allows the snake to swallow larger prey. The two halves of the lower jaw can also move independently of one another and are connected anteriorly by elastic ligaments. This allows the snake to have a gape of almost 180 degrees.

When the snake swallows its prey each side of the snake's jaw moves independently of the other. First the right side of the jaw moves forward along the long axis of the prey while it is held by the left side. The right side then closes on the prey and the left side moves forward. This has the effect of drawing the head of the snake over the prey. Retraction movements that would draw the prey into the oral cavity are energetically efficient only when the prey mass is small relative to the mass of the snake's head. The teeth are backwards sloping which stops prey moving back out of the mouth.

- Examine the modified **diapsid skull** (two openings in the skull roof). The cottonmouth (*Agkistrodon piscivorus*), an aquatic venomous snake found in the southern United States, has a highly reduced skull and cranial kinesis (bending) is possible. These are hollow fanged (front fanged) snakes. The fang is located on the maxilla. Compare the teeth of the cottonmouth with that of a constrictor.
- Examine the skeleton of the snake. The most obvious feature of snakes is that they are legless. Most snakes do not have any evidence of the pectoral or pelvic girdles, appendages or sternum. However, some families of snake do retain vestigial pelvic girdles. Snakes have over 100 to 350 **trunk vertebrae**. There are a smaller number of **caudal vertebrae**. The only cervical vertebra that is present is the **atlas**. All but the first two trunk vertebrae possess a pair of **ribs**. There are also numerous articulations which allow the vertebrae to be flexible yet strong. These extra articulations are on the neural arches called **zygosphenes** (anterior & faces down) and **zygantra** (posterior & faces up). There is also a **ball & socket** articulation between the centra of two different vertebrae. Again this helps to increase the strength of the vertebral column.

### ➤ Birds (Aves – chicken and pigeon)

- Examine the axial skeleton of both the chicken and the pigeon. Use figure 7 to assist you in locating the bones and structures that are in bold. Among vertebrates, birds show the greatest number of skeletal specializations for flight. The axial skeleton is greatly strengthened by fusions among the thoracic vertebrae, and the thoracics are fused with a large bony mass called the

**synsacrum** composed of thoracic, lumbar, sacral and caudal vertebrae. A few of the caudal vertebrae are fused to form the **pygostyle**, which support the tail feathers. The well-developed thoracic vertebrae have prominent **uncinate processes** which overlap adjacent ribs behind. They increase the surface area for muscle attachment and increase the rigidity of the axial skeleton. The **sternum** is a large bony structure, to the sides of which the ribs are firmly attached. The ventral portion is formed into a prominent **carina** which provides additional surface area for muscle attachment. Flightless birds lack a carina.

Birds have achieved light body weights in part by reducing the weight of the skeleton by either losing or reducing the size of some bones in the skull, limb girdles and limbs. More important is the **pneumatization** (contains air spaces) of many of the remaining bones.

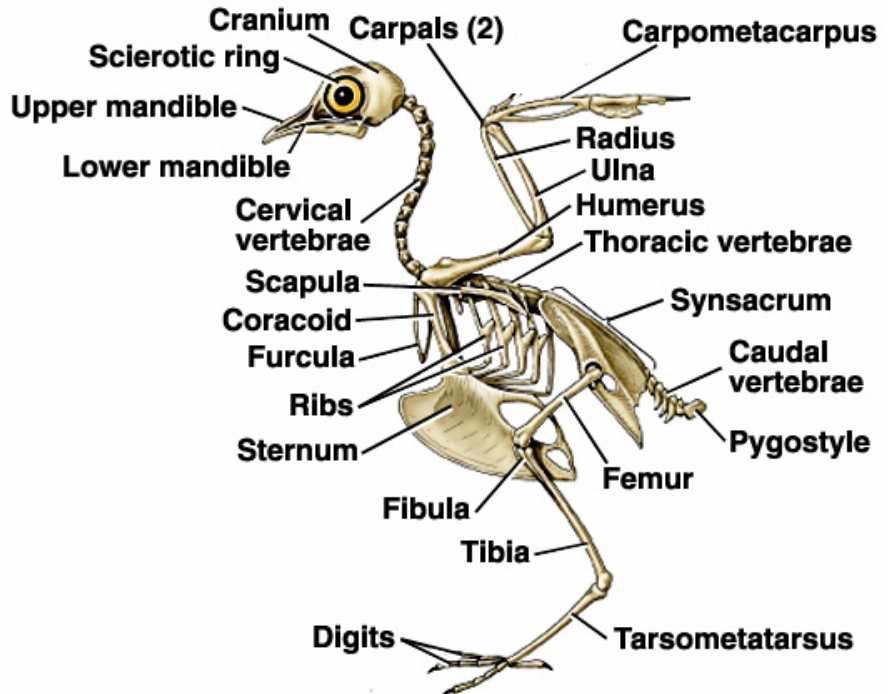


Figure 7: Bird skeleton

- Examine the pectoral girdle of a bird. Find the two large **coracoids** (which join the sternum) think narrow **scapula** and the slender **clavicles**. The clavicles fuse anteriorly with the **interclavicle** forming the **furcula** (wishbone). Located between all three bones is a hole called the **foramen triosseum** or trioseal canal. This provides a passageway for the tendon of the **supracoracoideus muscle** which inserts on the humerus. This muscle raises the wing while the much larger pectoralis provides the down stroke. The wings develop from the **humerus, radius** and **ulna**. These bones are larger than those of reptiles; however, the bones in the "wrist" and hand are reduced. Only two carpals are present and the others have fused to the remaining three **carpometacarpus**.
- Examine the relatively large pelvic girdle of a bird. It is designed to support the body weight when landing or moving on the surface. On each side, the large **ilium** projects anteriorly and posteriorly and is fused to the synsacrum along the latter's length. The **ischium** extends posteriorly, paralleling the ilium and fusing to it. The **pubis** is a long thin bar that is located ventral to the ischium and usually projects posterior to it. The legs and feet are adapted for **bipedal locomotion** and are specialized for running, swimming, wading, perching, capturing prey, etc. You examine the various types of feet in the Chordate lab a few weeks ago. The **femur** is very strong and is typically held close to the body. The "drumstick" comprises the **tibia** and the smaller lateral **fibula**. The **tarsometatarsus** is formed from the fusion of the distal tarsals with the second – fourth metatarsals.
- Examine the bird skull. It is a diapsid skull. The very large brain case (does not necessarily confer intelligence) is composed primarily of the **frontal** and **parietal** bones which also forms portions of the large eye socket. The bones are fused to support and protect the head structures with minimal weight. The **premaxilla** and **maxilla** make up the upper jaw. Find the thin **jugal** (zygomatic arch) below the eye socket. Posteriorly, the jugal articulates with the **quadrate**. The lower jaw is composed of five fused bones. The **dentary** is located anteriorly and the remaining four bones are often difficult to differentiate (angular, articular, surangular and splenial). Compare

the structure of the bones in the bird skull to that of the turtle. Compare the lower jaw to that of the turtles.

➤ **Mammals (Cat & Human) – Represents the synsapid skull (one lateral temporal opening)**

Changes in the skull structure of mammals are related to an increase in their behavioral repertoire and adaptations for more efficient feeding. Examine cat skulls (Figure 8) and compare to a human skull (Figure 9). The chondrocranium is completely ossified and a marked reduction in the number of dermal bones can be seen in both species. Evidence of reduction in bone number is exemplified by the lower jaw (now consisting only of the dentary) and the bones of the orbit. Some of the more complicated bone configurations of other classes have been lost or the bones have fused into single structures (compare the occipital region of a mammal to that of a bird or reptile). This reduction in the bone count is accompanied by a decrease in the number of **sutures** (joints between bony plates). These modifications further increase the skull strength.

- Examine the teeth of various mammals. Specialization of the teeth (**heterodont dentition** – more than one type of teeth) is evident as some became adapted for cutting (**incisors**), grinding, chewing (**premolars** and **molars**), and/or tearing (**canines** – compare mammalian teeth to those of the amphibian and fish). Carnivores has specialize fourth upper premolar and first lower molar that's used for tearing flesh called **carnassials**. Even within the mammals, skull architecture has been markedly affected by the nutritional requirements of the animal. Mammals that are missing the canines have a gap called a **diastema** (see lagomorphs, rodents, horses). Be able to identify teeth on various mammalian skulls.
- Examine the skull of the cat (Figure 8) and human (Figure 9). Find the following bones: **frontal, parietal, nasal, maxilla, premaxilla, dentary, temporal, zygomatic, and occipital**. Can you find the **quadrate** and **articular bones**? The zygomatic arch of the cat, for example, is proportionally larger than that of humans to make room for more muscle attachment sites for a strong bite for tearing flesh. Compare and contrast the structure of the human skull to that of the cat. How might anatomical differences be explained by the lifestyles of the organisms? Count the number of bones that make up the eye socket and describe any evolutionary trends you have detected in skull complexity.
- Examine other mammalian skulls and be able to identify the structures above in the dolphin, sea lion, rodent, rabbit, etc.

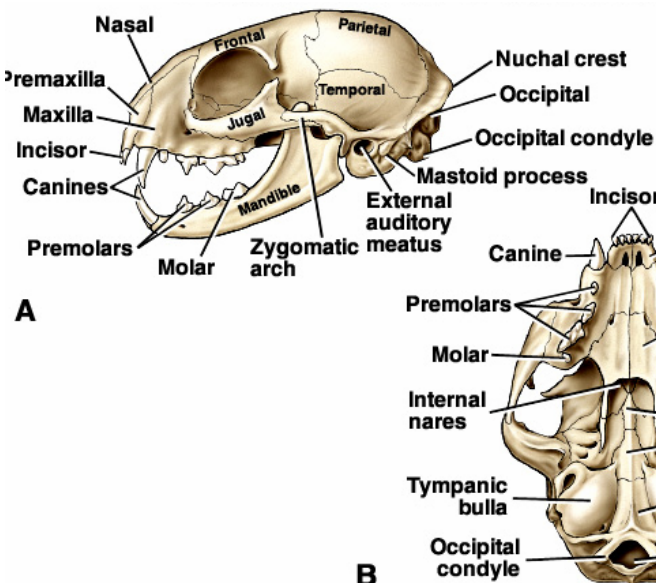
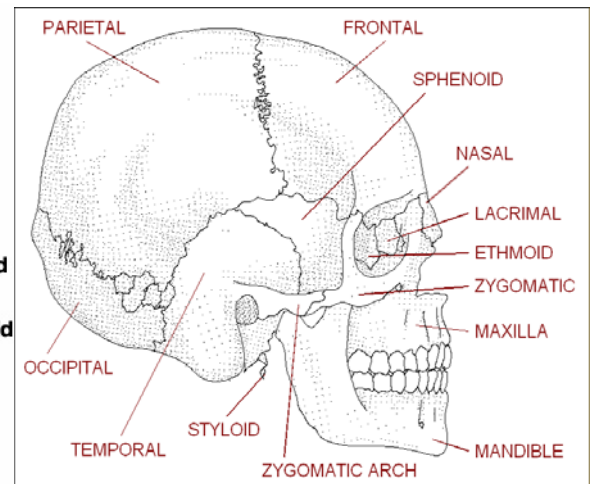


Figure 8 (left): Cat skull a) lateral view b) ventral view.

Figure 9 (below): Human skull (lateral view)



- Examine the remainder of the axial skeleton of the cat (Figure 10) and the human (Figure 11). You are responsible for the disarticulated vertebrae.
  - Cervical vertebrae – there are 7, with the first one called the **atlas** to support your nugget and the second is the **axis** which allows you to rotate your nugget. Each cervical vertebra has a **spinous process**. Their transverse processes have the **vertebral foramen** in which the vertebral artery passes. There are 12 **thoracic vertebrae** that bear the **ribs**. Notice that the spinous processes are quite long. The 5 **lumbar vertebrae** are very heavy compared to the other vertebrae. There is no transverse process. The spinous process is either rectangular or hatch-shaped and point backwards. The **sacral vertebrae** are fused forming the **sacrum** that provides a point of attachment for the pelvic girdle. The number of **caudal vertebrae** varies from species to species. We have 2-3 fused caudal vertebrae that form the **coccyx**.
  - Locate the **sternum** and differentiate between the **manubrium** (first segment) and the last segment, the **xiphisternum**. The **ribs** are attached to the sternum via the **costal cartilage**.
- Examine the appendicular skeleton of the cat and the human. Locate the following bones: **scapula, clavicle, humerus, radius, ulna, carpals, metacarpals, ilium, ischium, pubis, femur, patella, tibia, fibula, tarsals, calcaneus (a specific tarsal – the heel) and metatarsals**.

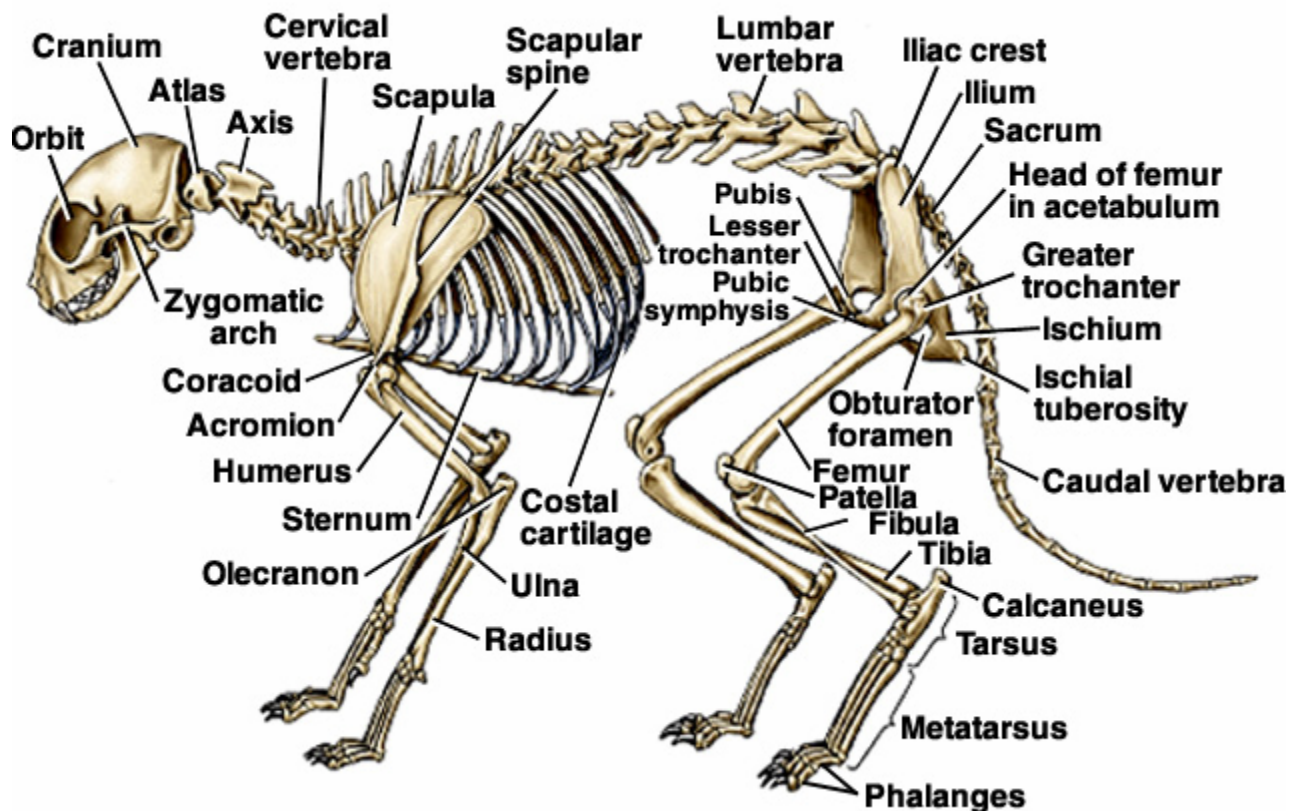
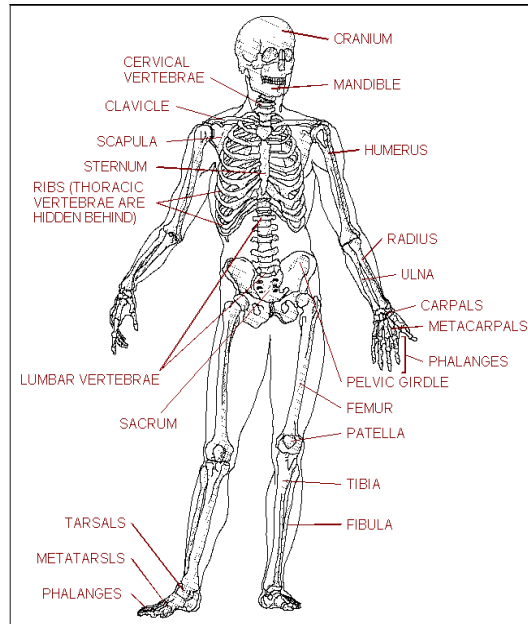


Figure 10: Cat skeleton.

Figure 11: Human skeleton

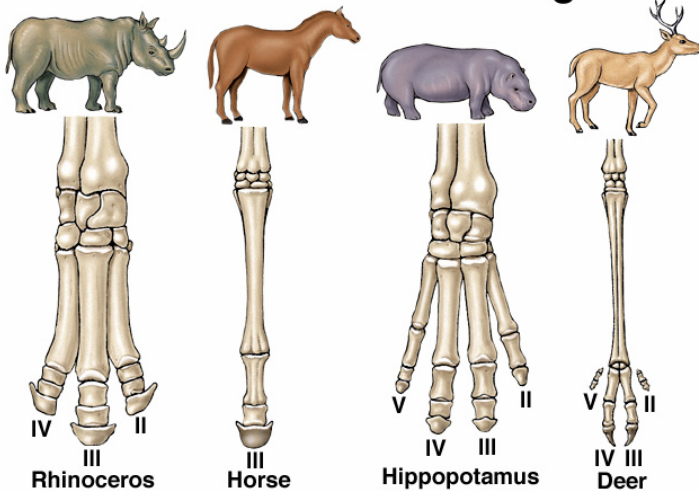


- Skeletal Adaptations.** Compare the pectoral (foreleg) and pelvic (hindleg) girdles of man and cat. What differences in limb structure do you see that appear to be directly related to high-speed pursuit and predation in the cat? Modification of these bones can lead to adaptation in locomotion. Among mammals, a number of carnivores and ungulates (hoofed animals) have evolved specializations for **cursorial locomotion** (very fast running). Running speed is based upon two basic factors: length of the stride and the speed of the limb movement. Examine the stance of your lab partners. This is the ancestral **plantigrade** stance – flat-footed. To increase stride length, you can increase the length of bones, particularly the **metapodials** (collective term for the metacarpals and metatarsals), elevating the carpus and tarsus to more or less stand on the digits (toes). Examine the cat’s stance. Notice that the cat is standing on the metapodials with most of its toes on the ground. This stance is called **digitigrade**. In digitigrade mammals, the first toe and metapodial are reduced or lost.

The front foot retains the first toe as a tiny **dew claw**.

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### Odd-toed and even-toed ungulates



The greatest increase in limb length is achieved with the **unguligrade** stance (Figure 12), in which the animal stands on the very tips of the toes, which are surrounded and cushioned by modified claws called **hooves**. Artiodactyls stand on their third and fourth toes which are of equal size. Their third and fourth metapodials are fused into the **cannon bone**. The cannon bone of horses is comprised of only the third metapodial. The second and fourth metapodials have been reduced to small nonfunctional **splint bones**.

Figure 12: Unguligrade bone structure

Links:

- <http://www.umanitoba.ca/faculties/science/zoology/faculty/horn/z232/labs/labs.html>
- <http://campus.murraystate.edu/academic/faculty/terry.derting/anatomyatlas/>