ZOO 4377L - VERTEBRATE MORPHOLOGY LAB

LAB 4: THE AXIAL SKELETON - POST-CRANIAL

Name: _____ SSN: _____

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Next Week's Assignment: Walker & Homberger - Chapter 6; **also paragaph 2 of page 48 (limb orientation)**

Preparation: W & H, Chap. 5

Background

The vertebrate skeleton can be divided into two components: The axial and appendicular. The axial skeleton consists of the cranium, vertebral column, ribs and sternum whereas the appendicular skeleton consists of the limb bones. Today we will examine the post-cranial portion of the axial skeleton (i.e., vertebral column, ribs and sternum). In contrast to the skull, which contains a large proportion of both dermal and endochondral bones, the bones of the post-cranial axial skeleton are composed almost entirely of endochondral bone.

The skeleton serves as a storehouse for various minerals necessary for metabolism, protects internal organs, provides a rigid structure for the body, and, due to its segmented, hinged nature, combines with associated muscles for locomotion. The protective function of the axial skeleton is particularly important with the cranium enclosing the brain, the vertebral column enclosing the spinal cord and the ribs and sterns protecting the heart and lungs. In contrast to the rigid exoskeleton of terrestrial arthropods, the internal skeleton (endoskeleton) is less cumbersome and has allowed vertebrates to reach much larger sizes while remaining relatively agile.

In today's lab we will examine the modifications seen in the axial skeleton relating to life in water (fishes) vs. life on land (tetrapods). You will be responsible for knowing all structures whose name appear in **bold** for next week's quiz.

Do not be intimidated by the strange names given to the processes projecting from the vertebral bodies and arches that serve for articulations or muscle attachment. They all share a common root, apophysis (G. απο = φυσις, *away, out + growth*), and thus differ only in their descriptive prefix, e.g., zygapophysis, diapophysis, parapophysis, etc.

The vertebral column of any vertebrate otentially can produce 3 types of movement:

1) lateral flexion (bending) - approximation of the lateral margins
2) flexion and extension - approximation of the ventral and dorsal margins, respectively
3) rotation - pivoting of the vertebra relative to one another along the longitudinal axis

Typically while the amount of movement that occurs between adjacent vertebra is small, the total effect is *cumulative*. Thus, if only 4^{o} of lateral flexion are possible between adjacent vertebra, then in a series of 24 vertebra the total amount of flexion between the first and last vertebra of the series will be 96 ^{o} = (4 x 24).

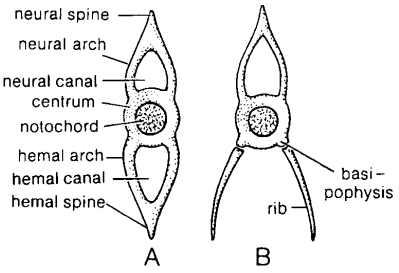
? In class exercise: Using a series of boxes (□ □ □ □) to represent the individual vertebrae of a vertebral column, illustrate the movements involved in 1) lateral bending (dorsal/ventral view), flexion/extension (lateral view) and (3) longitudinal rotation (cranial/caudal view).

lateral flexion (dorsal view)	flexion/extension (lateral view)	longitudinal rotation (cranial view)

1) Fishes (W & H, pp. 95-99)

The vertebrae of fish aid in the undulations of swimming. In the absence of gravitational forces, the entire vertebral column is subjected to similar stresses and, therefore, shows little regional differentiation. Two basic types of vertebrae can be identified, trunk vertebrae and caudal vertebrae. The latter are modified to protect the caudal artery and vein from being compressed by the locomotory muscles of the tail.

Examine the vertebra of the perch (*Perca falvescenes*) skeletal mount. Using the accompanying figure, (Hymen 6.3A&B) make a sketch of a single **trunk** and single **caudal vertebra** in both lateral and cranial views. Label **and** define the following:



vertebral body (= centrum)
notochord
vertebral arch (= neural arch)
vertebral foramen / canal
spinous process
hemal arch
hemal canal
basapophyses
ribs

trunk vertebra
cranial view lateral view

caudal vertebra
cranial view lateral view

Note that the trunk vertebra have two types of ribs: 1) small, gracile *intermuscular ribs* which extend between the epaxial and hypaxial musculature and 2) larger, more robust *subperitoneal ribs* which project into the myosepta adjacent to the body cavity.

? The centra are morphologically classified as amphicoelous. What shape are the cranial and caudal ends of the centra? What does amphicoelous mean?

? How many trunk vertebra are there?

? How many caudal vertebra are there?

? What feature(s) distinguish the trunk and caudal vertebra?

? What bony feature(s) of the vertebra may limit the amount of vertebral flexion?

? What bony feature(s) of the vertebra may limit the amount of vertebral extension?

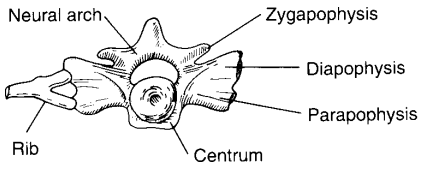
? Are there any bony features that limit lateral flexion (bending) ?

? Based on the last three observations, which movement do you think is the major movement involved in fish locomotion, i.e., is it lateral flexion, extension or flexion? What other non-vertebral features suggest that this is the case?

2) Primitive Tetrapods (W & H pp. 99-102)

As tetrapods moved onto land, the body skeleton became increasingly important for support and locomotion. In response to greater gravitational stress, tetrapods show (1) greater ossification of the axial skeleton than do fishes and (2) the development of intervertebral articulations (zygapophyses). The vertebral column also shows further regional differentiation into cervical, trunk, sacral, and caudal vertebrae. In this section we will determine how a transition to terrestrial life has reshaped the axial skeleton by examining an amphibian, the mudpuppy, *Necturus machlosus*. While *Necturus* is secondarily aquatic as an adult, it's ancestors were fully terrestrial as adults, and this is reflected in its terrestrial-like vertebrae. The advantage of examining *Necturus* therefor lies in its large size, as most salamanders are very much smaller. In comparison to salamanders, the axial skeleton of the other amphibians (frogs and caecilians) are highly derived.

Examine the vertebra of the mudpuppy (*Necturus machlosus*)) skeletal mount. Using Fig. 5-4 (lateral view) and the accompanying figure (cranial view; W&L 8-6b), make a sketch of a single **trunk vertebra with ribs** in lateral and cranial views. Label **and** define the following:



vertebral body
vertebral arch
- **vertebral canal**
- **spinous process**
- **pre-zygapophyses (cranial)**
- **post-zygapophysis (caudal)**

"transverse process"
- **diapophysis**
- **parapophysis**

rib
- **caput**
- **tuberculum**

lateral view

cranial view

Identify the 4 types of vertebra: **cervical**, **trunk**, **sacral** and **caudal**

? How many **cervical vertebra** are there in *Necturus*? How could it be identified in isolation? Why is the first cervical vertebra called **atlas**?

? How many **trunk vertebra** are there in this specimen of *Necturus*? How could they identified in isolation?

? How many **sacral vertebra** are there in this specimen of *Necturus*? How could they identified in isolation?

? How many **caudal vertebra** are there in this specimen of Necturus? How could they identified in isolation? [Hint: Two criteria.]

? In which direction do the articular surfaces of the pre-zygapophyses face (not the whole process)? In which direction do the articular surfaces of the post-zygapophyses face (again, not the whole process)? A simple way to remember these orientations is to recall that the post-zygapophyses are "down and out" because they "tail" the pre-zygapophyses.

? Note that the ribs of Necturus are abbreviated. In most air-breathing terrestrial vertebrates the ribs are elongated and function in thoracic breathing, i.e., movement of the ribs is used to expand the pleural cavities during inspiration thus drawing air into the lungs. Why might the ribs of *Necturus* be abbreviated?

? Assuming the ribs (*intermuscular ribs* and *subperitoneal ribs)* of the perch to be the ancestral condition, how might the single, bicipital ribs of *Necturus* be derived from a 2 rib character state?

? Note that both ends of the vertebral body in *Necturus* are concave. Which of the following terms correctly describes this morphology: acoelous, amphicoelous, opisthocoelus, procoelous?

3) Mammals (W & H, pp. 102-110)

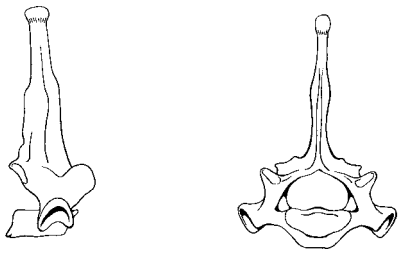
Mammals show the most regionalization of the vertebral column. The vertebral column is vital not only to locomotion and for protection of the spinal cord, but also as an integral part of abdominal (diaphragmatic) respiration. The vertebral column is differentiated into cervical, thoracic, lumbar, sacral, and caudal vertebrae. *Be sure to be able to identify the five different vertebral types of mammals as well as the terms listed below.*

Examine the vertebra of the cat (*Felis catus*) skeletal mount. Make a sketch of a single **thoracic vertebra** in lateral and cranial view using the accompanying figure (G&Scat3). Use W&H Figures 5-7 and 5-8 to label **and** define the following structures:

vertebral body
vertebral arch
- **pedicle**
- **spinous process**
- **vertebral foramen / canal**
- **pre-zygapophyses**
- **post-zygapophyses**
- "transverse process" **(diapophysis)**

rib
- **tubercle**
- **head (captiulum)**

lateral view cranial view



? Note that when 2 adjacent vertebra articulate, their pedicles form an **intervertebral foramen**. What structure "exits" through this foramen?

? Mammalian vertebral bodies are typically described as being **acoelous**. What does this mean?

? How many **cervical vertebra** are present? How could they be identified if disarticulted?

? What is the special name given to the **first cervical vertebra** (C1) ?

? What is the special name give to the **second cervical vertebra** (C2) ? Note the cranially projecting dens or odontoid process (W&H Figure 5-7).

? How many **thoracic vertebra** are present? How could they be identified if disarticulted?
? How many **lumbar vertebra** are present? How could they be identified if disarticulted?

? How many **sacral vertebra** are present? How could they be identified in isolation?

? How many **caudal vertebra** are present? How could they be identified if disarticulted? Can you seen a hemal processes on any of the caudal vertebra. These are points of articulation

with the cartilaginous hemal arches which protect the caudal artery and vein. The arches, being cartilage, are typically lost in the process of skeletonization.

Mammalian Ribs and Sternum. (W & H, Fig. 5-9)

In terrestrial vertebrates, ribs serve a much more important role in support and locomotion than in fishes. Additionally, in amniotes (reptiles, birds, mammals), ribs have become vital to the expansion of the thoracic cavity during breathing. As a result, the ribs of amniotes show various differentiation's that allow for the insertion of intercostal muscles. Some ribs have costal cartilages that connect ventrally with the sternum, another member of the axial skeleton. This connection forms a strong but flexible box which is helpful in absorbing the intense shock produced in the pectoral girdle by running quadrupeds as the forelimbs strike the ground.

Make a sketch of a cat rib in caudal view using W&H Figure 5-8 as a guide. Label **and** define the following:

caudal view

head
neck
tuberculum
angle
body

? How many vertebrosternal ribs are present? What are their designations (e.g., R1 = first rib, R2 = second rib, etc.,)?

? How many vertebrochondral (= vertebrocostal) ribs are present? What are their designations?

? How many vertebral or "floating" ribs are present? What are their designations?

Identify the 3 elements of the **sternum**:

manubrium - the cranial-most sternebra
body or gladiolus
xiphisternum - the caudal-most sternebra
xiphoid process - cartilaginous

? How many sternebra (including the manubrium and xiphisternum) are present in the cat?

[The elements of the sternum are named for their shape in the human condition. Collectively they resemble a sword. Thus, we have the handle (manubrium), body of the blade (gladiolus; from which we derive gladiator), and the sword-like (xiphoid) tip.]

4) Vertebral movements - Mammalian

In front of you are the three caudal most lumbar vertebra and the cranial most 1.5 sacral vertebra from a juvenile deer (*Odocoileus virginianus*). Articulate the 2 cranial- most lumbar vertebra and attempt the following movements:

1) flexion
2) extension
3) lateral flexion or bending
4) rotation (longitudinal)

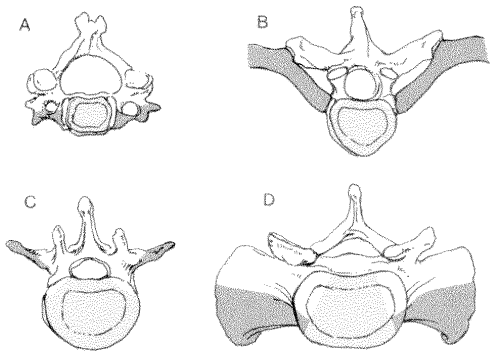
? Rank order these movements from greatest to least. Is any amount of longitudinal rotation possible?

? For each of the above movements, note which parts of the vertebra appear to limit each movement.

? Why might longitudinal rotation be undesirable in the lumbar region of a quadruped? [Hint: Think about the effect of alternately planting the left and right hindlimbs during locomotion.] Why is a block to longitudinal rotation not necessary in the vertebral region adjance to the forelimbs?

5) Human Vertebra

The accompanying figure (CHS 2-3) shows a human cervical (A), thoracic (B), lumbar (C) and sacral vertebra in cranial view. Each shows the contribution made by the three major embryonic elements to each of the vertebral types: Light stipple = centrum, dark stipple = costal element, and clear = arch. [Realize that the both the arch and centrum actually develop from a larger number of elements but are shown simplified here.] Note that all vertebra have a costal element or "rib" and it's the (1) relative size and (2) degree of fusion of the costal element that primarily distinguishes vertebral types. The fact that all vertebra share the same embryonic components (despite variation in appearance) is an illustration of **serial homology**.



In front of you are 6 human vertebra: Using the information above and incorporating your knowledge from the cat vertebral column, state to identify following in isolation (i.e., disarticulated):

? a) C1 or atlas

? b) C2 or axis

? c) cervical vertebra (C3-7)

? d) thoracic vertebra

? e) lumbar vertebra

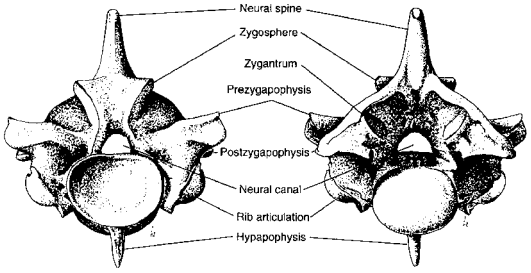
? f) sacrum (sacral vertebra)

6) Sauropsids

Among the sauropsids (sister group of synapsids), there are three groups which have highly derived axial skeletons: the turtles, the snakes and birds. In this section we will examine four groups of sauropsids using the alligator (*Alligator mississippiensis*) as representing the ancestral sauropsid condition.

Alligator - in progress

Snake



The elongated body of a snake may contains between 160 to 400 vertebrae. Snakes move primarily by lateral undulatios of the trunk and tail. Snakes posses an additional set of articular processes (in addition to the pre- and post-zygopophyses) called the zygosphene and zygantrum (see accompanying figure (2K8-30m)). These processes additionally serve to limit longitudinal rotation. Aside from the atlas-axis complex (C1-C2) and the tail (caudal vertebra), distinct vertebral regions cannot be recognized, thus the majority of vertebrae are classified as thoracic. All vertebrae except atlas and the caudal (post-cloacal) ones bear ribs that curve ventrally and end freely (there is no sternum). In addition to their respiratory function, rib movements are important in supporting the body and in locomotion.

? In front of you are a series of snake vertebra from a cobra (sp?). Using an articulating pair of vertebra, rank order the following movements from greatest to least: flexion, extension, lateral flexion, longitudinal rotation

? Based on your observations, what vertebral movement would appear to be the major action in snake locomotion?

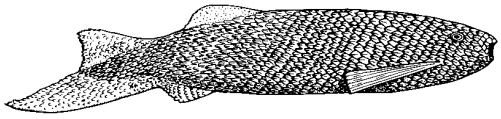
? Why might longitudinal rotation be undesirable in the limbless snake?

? Using the rule of "down and out" for the post-zygopophyses, is the zygosphene cranial or caudal? This would make the zygantrum cranial or caudal?

? Note that the ends of the vertebral bodies are asymmetrical. Using the rule of "down and out" for the post-zygopophyses, which of the following terms correctly describes this morphology: acoelous, amphicoelous, opisthocoelus, or procoelous?

Bird - in progress

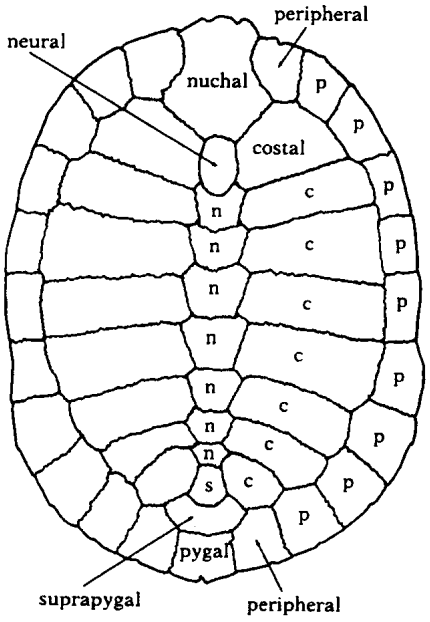
7) Turtle Shell



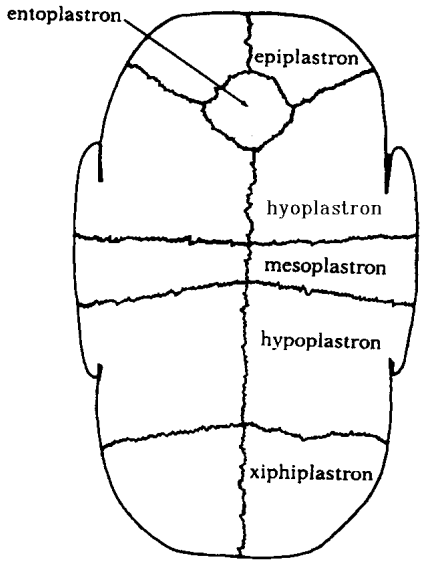
You will recall that the last common ancestor of all living craniates (the ancestral euagnathan) was entirely encased in a bony exoskeleton consisting of dermal ossifications (shown is the fossil pteraspidomorph *Phlebolepis*). This bony covering has been reduced in or lost in most extant craniates but all gnathostomes retain portions of the ancestral exoskeleton in their skull and pectoral girdle (for example, your dermatocranium and portions of your clavicles). However, in a few cases some amniotes have re-evolved a nearly complete exoskeleton. Perhaps the most striking example of this is seen in front of you, the turtle shell. Unlike the ancestral exoskeleton, however, the turtle shell incorporates portions of the endoskeleton within it, a clear indication of its independent origin.

? What other amniotes have re-evolved a nearly complete exoskeleton? [Hint: It's a common road-kill in Central and North Florida and there is a recipe for it in "Jane Nickerson's Florida Cookbook."]

The turtle shell consists of approximately 60 bony plates and is divided into a dorsal carapace and a ventral plastron which are joined together on each side by a bridge (actually part of the plastron). Since its appearance 220 mya, the turtle shell has changed remarkably little. The plates can be *simple* (derived from a single ossification) or *compound* (derived from multiple ossifications). In the carapace, the compound plates represent fusions of the axial endoskeleton (endochondral bone) to dermal ossifications, whereas in the plastron they represent fusions of dermal pectoral elements to dermal ossifications. The plates articulate with one another at fibrous joints called *sutures*.



Carapacial bones of turtles



Plastral bones of turtles

Use the accompanying figure to identify the following elements of the carapace:

midline series
- **nuchal** (G. neck)
- pre-neural - absent in most species
- **neurals** - compound plates consisting of neural arches fused to an overlying dermal plate
- suprapygals
- **pygal** (G. tail)

intermediate series:
- precostals - absent in most species
- **costals** - compound plates consisting of costae (ribs) and overlying dermal plate

peripheral series:
- peripherals

? How can you distinguish the *nuchal* from a *pre-neural* from a *neural*?

? How can you distinguish a *neural* from a *suprapygal* from the *pygal*?

? How can you distinguish a *precostal* from a *costal*?

? Using your criteria, enumerate the number of each type of elements in the disarticulated carapace. Remember, not all species have all types of each element:

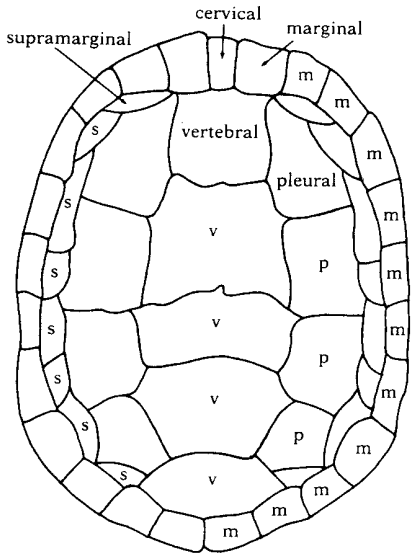
nuchal	_____
pre-neural	_____
neural	_____
suprapygals	_____
pygals	_____
precostals	_____
costals	_____
peripherals	_____

Use the accompanying figure to identify the following elements of the plastron [G. emplastron (εμπλαστρον) - plaster or mold]. Note that all of these names consist of the root word *plastron* with a descriptive prefix.

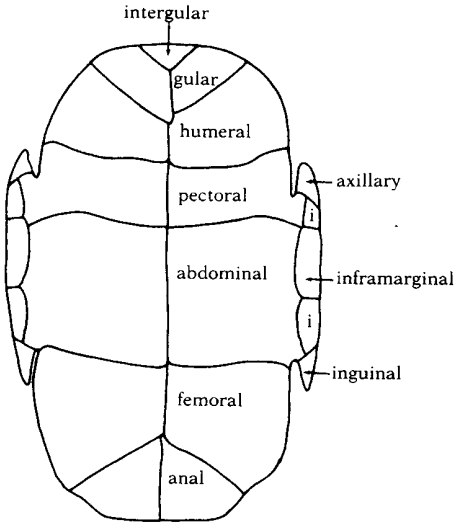
entoplastron (G. within, inner) - compound plate containing the interclavicle
epiplastron (G. upon) - compound plate containing the clavicle
hyoplastron (G. U-shaped)
mesoplastron (G. middle) - absent in most species
hypoplastron (G. under)
xiphiplastron (G. sword)

? What plastral elements (assuming no mesoplastron) contribute to the bridge of the shell?

In life, the shell is covered with a layer of horny epidermal scales known as scutes and it is the pigmentation within the scutes that gives each shell is characteristic coloring. Scutes from a peninsula cooter (*Pseudemys floridana peninsularis*) are available for examination.



Carapacial scutes of turtles



Plastral scutes of turtles

The division between adjacent scutes are called *seams* and they produce a *sulcus* (L. groove) on the underlying bone. Close examination of the shells will show you that the pattern of scutes (marked by sulci) and plates (marked by sutures) does not match (i.e., there is no one-to-one correspondence between scutes and plates). The accompanying figure identifies the names of the carapacial and plastral scutes. As with the plates, the number and type of scutes present varies among species (and probably individuals).

Optional excercise: Interestingly the relative lengths of the plastral scutes along the midline can provide some information as to species: Using the sliding calipers (CAREFULLY) or similar device, measure the midline length of the plastral scutes (as indicated by the sulci) of the two shells and record your measurement on the chart below: Then rank order the scutes (e.g., anal > pect > fem = gular > humeral > abd) by decreasing size and see if you can determine which shell is a peninsular cooter (*Pseudemys floridana peninsularis*) and which is a red-bellied slider (*Pseudemys rubriventris*).

	Shell A (articulated)		Shell B (disarticulated)	
	left	right	left	right
anal	_____	_____	_____	_____
femoral	_____	_____	_____	_____
abdominal	_____	_____	_____	_____
pectoral	_____	_____	_____	_____
humeral	_____	_____	_____	_____
gular	_____	_____	_____	_____

Shell A rank order:

Shell B rank order:

peninsular cooter (*Pseudemys floridana peninsularis.*): abd > anal > gul > pect > fem >< hum

red-bellied slider (*Pseudemys rubriventris rubriventris.*): abd > anal > gul > pect ><fem > hum

? Which shell better matches the cooter? The slider?