ZOO 4377L - VERTEBRATE MORPHOLOGY LAB

LAB 5: APPENDICULAR SKELETON

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Next Week’s Assignment: Walker & Homberger - Chapter 4 (The Head Skeleton)

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Preparation: Walker & Homberger - Chapter 6; also paragraph 2 of page 48 (limb orientation)

Background

The appendicular skeleton consists of the skeletal supports of the paired fins of fishes, the limbs of terrestrial vertebrates, and the pectoral and pelvic girdles which attach the appendages to the body wall. The presence of paired appendages is a synapomorphy that unites the Gnathostomata (the chondrichthyes and osteichthyes including tetrapods; i.e., all the craniates excluding the "agnathans"). The appendicular skeleton is composed mostly of cartilage or endochondral bone although some dermal bone contributes to the pectoral girdle of most species. The nomenclature which is used for the skeletal elements of the limb is shown at right (limb-nom.tif).

Today’s Lab

In today’s lab we will examine the modifications seen in the appendicular 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.

This lab is composed of 8 stations (the 8th is optional). The first three examine the appendicular skeletons of a fish, primitive tetrapod (Necturus) and derived tetrapod (Felis catus). In the fourth and fifth stations you are asked to identify homologous bones and processes in 2 additional mammalian limbs. The sixth (observation only) exhibits an example of a vestigial limb. The seventh station will be performed as an in-class exercise at the end of lab.

0) In preparation for studying changes in limb posture, we’ll go over the exercise “Mammalian Limb Rotation” as a class. This exercise can be found at the end of the handout. The exercise will require a piece of paper and a piece of modeling clay.

1) Cartilaginous fish (W & H, pp. 111-115)

The appendicular skeleton of Squalas is reasonably representative of the type found in many living fishes with the caveat that it is cartilaginous rather than bony. For this reason, the dermal elements of the pectoral girdle are missing in the chondrichthyes. Using Figure 6-3 of your lab manual, sketch the pectoral and pelvic fins and label the following:
Identify:

**pectoral fin**
- suprascapular cartilage
- scapulocoracoid
- glenoid fossa or surface
- scapular process
- coracoid bar
- pterygiophores
  - basal
  - radial
  - ceratotrichia

**pelvic fin**
- puboischiadic bar
- acetabulum
- iliac process
- pterygiophores
  - basal
  - radial
  - ceratotrichia

? What type of tissue (i.e., skeletal (cartilage) or soft?) appears to attach the suprascapular cartilage to the vertebral column?

? What articular surface marks the border between the scapular process and coracoid bar?

? How many basal pterygiophores are found in the pectoral fin? In the pelvic fin? What are their names? Which of these is thought to be homologous to the stylopod of the tetrapod limb? What is the basis for this hypothesised homology?

? Look up the roots of the term pterygiophore (i.e., pterygio- + phore-) in Brown’s *Composition of Scientific Words*. What do they mean?

? What articular surface is found on the puboischiadic bar? Look up the root of this term in Brown’s *Composition of Scientific Words*.

? What sex is this skeleton? How can you tell? (Figure km10-8)

2) **Primitive Tetrapod Condition** (W & H, pp. 117 -118)
Amphibians and many living reptiles retain rather primitive features of both the pectoral and pelvic limbs. In this section we will determine how a transition to terrestrial life has reshaped the pectoral and pelvic fins into pectoral and pelvic limbs by examining an amphibian, the mudpuppy, *Necturus machlosus*. Among the amphibians, salamanders, like many living reptiles, retain rather primitive features in both their pectoral and pelvic limbs, and thus can be viewed as representing the primitive tetrapod condition. While *Necturus* is secondarily aquatic as an adult, its ancestors were fully terrestrial as adults, and this is reflected in its terrestrial like appendages. The advantage of examining *Necturus* therefor lies in its large size, as most salamanders are very much smaller. As was the case in the axial skeleton, the appendicular skeleton of the other amphibians (frogs and caecilians) are highly derived.

Examine the pectoral and pelvic limbs of the mudpuppy (*Necturus machlosus*) skeletal mount. Using Figure 6-7 of your lab manual, sketch the fore- and hind-limbs and label the following:

**Identify:**

**Forelimb**
- pectoral girdle
- scapula
- glenoid fossa
  - coracoid plate - cartilaginous; not preserved
- humerus
- radius
- ulna
- carpals
- metacarpals
- phalanges

**Hindlimb**
- pelvic girdle
- ilium
- acetabulum
- puboischiadic plate
- ischium
  - pubis - cartilaginous; not preserved
- femur
- tibia
- fibula
- tarsals
- metatarsals
- phalanges

Note that parts of the girdles and limbs in *Necturus* are only partially ossified (like a shark’s). What common environmental feature do both dog sharks and *Necturus* share? What would be the advantage of leaving the cartilage unossified?

For examples of pectoral and pelvic girdles in a primitive tetrapod that are completely ossified, examine those of the alligator (*Alligator mississippiensis*).

In what plane (see Figure N-1 on page xii) does the long axis of the brachium (= stylopod)? In what plane does the long axis of the antebrachium (= zygodop) lie? Note that in such a sprawling posture, only one segment of the limb contributes to the
excursion of the limb (stride length) during locomotion, in this case the brachium (= stylopod) which moves from a protracted (flexed) to retracted (extended) position during its stride. Also, note that the proximal articular surface of the brachium lies directly on the proximal end of the shaft.

? In the antebrachium (=zygopod), which bone lies pre-axially (i.e. cranially)?

? How many digits does the manus have? Given the ancestral condition is for five digits, which of the original five digits is believe to be lost in extant amphibians? What famous cartoon family has only four digits on their manus?

? What is the phalangeal formula of the right manus (=autopod; the left is damaged and incomplete)?

? In what plane (see Figure N-1 on page xii) does the long axis of the femur (thigh; =stylopod) lie? In what plane does the long axis of the shank (leg; = zygopod) lie? As in the forelimb, only the proximal segment of the limb (the femur) contributes to the excursion of the limb (stride length) during locomotion.

? In the shank (leg; = zygopod), which bone is pre-axial (i.e., cranial)?

? How many digits does the pes (=autopod) have? Given the ancestral condition is for five digits, which of the original five digits is believe to be lost in extant amphibians?

? What is the phalangeal formula of the right pes (=autopod; the left is damaged and incomplete)? Is it the same as the manus?

3) Derived Tetrapod Condition (W&H pp. 124-132)

In both birds and mammals the limbs are oriented so that they lie beneath the body rather than extending from it, as is the case in fish and primitive tetrapods, giving these organisms an erect (rather than sprawling) posture. The functional consequences of this change in orientation will be addressed below.

Examine the fore- and hind-limbs of the cat (Felis catus) skeletal mount. Work through pages 124 - 132 of your manual to identify the following bones and landmarks. Using Figure 5-5 sketch the forelimb and hindlimb skeletons (including girdles) and label the following:

forelimb
   "scapula"
   coracoid process (homolog of posterior coracoid)
   scapular spine (spinous process )
   acromion
   metacromion
   glenoid fossa
   clavicle
humerus  
  head  
  trochea  
  capitulum
ulna  
  olecranon [process]
radius  
  head
carpals
pisiform
metacarpals
phalanges

hindlimb  
os coxa
  ilium
  ischium
  pubis
  acetabulum
  obturator foramen
femur  
  head
patella
tibia
fibula
tarsals
  talus (astragulus)
calcaneus
metatarsals
phalanges

N. B. Before answering the following questions, you should probably work through the “Mammalian Limb Rotation” worksheet attached at the end of this handout, if you have not already done so.

? In both the pectoral and pelvic girdles of mammals and birds, many of the individual bony elements have fused together (e.g., in mammals the os coxa results from the fusion of the ilium, ischium and pubis and the “scapula” from the scapula (proper) and (posterior) coracoid. What might the advantage of fusion be? What is the consequence of such fusion in terms of growth?

? Does the scapula have a direct attachment (i.e., articulation) to the axial skeleton? If not, what attaches the scapula to the axial skeleton? [Hint: See Figure 7-24.]

? In what plane does the long axis of the brachium (stylopod) lie? In what plane does the long axis of the antebranchium (zygopod) lie? How does this arrangement differ from *Necturus*? Note that in such a posture, both the stylopod and zygopod (and possibly the autopod, if the organism is digitigrade; see below) now contribute to stride length. Finally, note that the proximal articular surface of the brachium (and femur) is offset medially.
In front of you is a pseudo-fossil representing the stylpod of a fossil tetrapods. Examining its proximal end, what can you deduce about the posture of this organism? Why?

Examine the skeletal elements of the antebrachium (zygopod). At the proximal end, which bone is lateral-most? Distally, which bone is lateral-most? Why do the bones of the antebrachium cross?

How many digits are there on the manus (autopod)? What is the phalangeal formula?

Of the 7 named carpal bones, which is a sesamoid bone?

What skeletal elements of the manus contact the substrate? For this reason, cats are said to have digitigrade posture. If the entire autopod contacted the ground they would be plantigrade.

Which bone of the os coxa articulates with the sacrum?

In what plane does the long axis of the thigh (femur; = stylopod) lie? In what plane does the long axis of the shank (leg; = zygosopod) lie? How does this arrangement differ from Necturus?

In the shank (leg), do the 2 skeletal elements cross? Why not? Which is lateral and which is medial?

Which of the shank (leg; = zygosopod) bones articulates with the femur? What other bone articulates with distal condyles of the femur?

Which of the tarsals forms the talo-crual (“ankle:) joint? Which of the tarsals forms the heel? What is the root of the latter term (see Brown’s Composition of Scientific Words)?

How many digits are there on the pes (= autopod)? What is the phalangeal formula?

4) Horse (Equus caballus) limb

First, before reading any further, is this a forelimb or a hindlimb? Explain your choice:

Based on your superb knowledge of cat skeletal anatomy and your razor-sharp prowess in establishing homologies, be prepared to identify the following structures:

scapula
coracoid process (homolog of posterior coracoid)
scapular spine (spinous process)
glenoid fossa

humerus
  head
  trochea
  capitulum
  olecranon fossa

ulna
  trochea notch
  olecranon [process]

radius
  head

carpals
  pisiform

metacarpals

phalanges

¿ Is there an acromion in the horse?

¿ What is different about the articulation between the radius and humerus in the horse as opposed to the cat? [Hint: In the cat, the radius articulates with what part of the distal humerus? What parts of the distal humerus does the horse radius articulate with?] Why might this be?

¿ Compared to the cat, what is the relative mobility between the radius and ulna in the horse?

¿ How many metacarpals are present? How many digits? What is the phalangeal formula of the manus?
5) Human fore- and hind-limbs

Based on your superb knowledge of cat skeletal anatomy and your razor-sharp prowess in establishing homologies, be prepared to identify the structures listed for the cat in section 3 above.

? Can you find a metacromion on the human scapula? This is a muscular process (i.e., a bony projections that serves as an attachment site for a muscle). Speculate as to the human condition in terms of presence or relative size of the cat muscle that attaches to the metacromion.

? In all quadrupedal mammals the pisiform is enlarged and posteriorly projecting (see cat and horse). It lies within the tendon of the flexor carpi ulnaris muscle which is a major flexor of the wrist joint. Hypertrophy of the pisiforms increases the moment arm of the muscle and hence its rotational force (torque) output. Look at the pisiform in the human hand. Why isn't it hypertrophied?

6) Whale hindlimb (observation only)

In cetaceans the pectoral limb has been modified into a flipper (see overlay) which acts as a hydrofoil. The clavicle is absent. Except for the glenohumeral ("shoulder") joint, all articulations are fibrous and virtually immovable. The radius, ulna and digital elements are greatly flattened and the phalanges of the second and third digits always exceed the normal number (hyperphalangism). The pelvic limb is greatly reduced and has lost contact with the vertebral column. In all whales a vestigial os coxa is found. Among the toothed whales (Odontoceti) a vestige of the femur is present only in the sperm whale. Among the baleen whales (Mysticeti) a vestigial femur is present, and in some species a vestigial proximal tibia is retained. The cetacean os coxa is extremely variable in form (see figure) and is always larger in males, not infrequently being absent in females. The size difference is due to the larger perineal muscles (associated with the penis) found in males. The identity of the bony elements (ilium, ischium and/or pubis) that contribute to the cetacean os coxa is disputed.

On display is the left os coxa from a male beaked whale (Mesoplodon europaeus) which beached on Stock Island, FL in October of 1998. The whale was 4.2 meters in length and weighed approximately 390-550 kg. Compare its size to that of your own os coxa. How long are you and how much do you weigh? Do you think that this is a vestigial organ?
7) In-class excercise: Advantages (and costs) of an erect posture

You may wish to ask your instructor for assistance in this section. Let’s compare two organisms, one with a sprawling posture (e.g., *Necturus*) and one with an erect limb posture (e.g., *Felis*; Figure 2K9-32). We will make the following assumptions:

1) both organisms are of equal mass
2) both organisms have equal limb lengths (distance from proximal stylopod to distal autopod)
3) all limbs segments are of equal length (stylopod = zygopod = autopod)
4) both organisms have equal stride frequencies (see below)
5) in both organisms the center of mass lies at the point midway between the acetabulum and glenoid fossa

**An advantage of erect posture**: Recall that in pedal locomotion
\[ \text{velocity} = \text{stride length} \times \text{stride frequency} \]

? How many limb segments contribute to **stride length** in the organism with sprawling posture?

? How many limb segments contribute to **stride length** in the organism with erect posture?

? Recall that stride frequency is assumed to be equal between the two organisms, which will be faster (achieve a higher velocity)? Why?

? Among organisms with erect posture, assuming equal total limb lengths and equal stride frequencies, which will be faster, digitigrade or plantigrade organisms? Why?

**A cost of erect posture**. Recall that:
\[ \text{force} = \text{mass} \times \text{acceleration} \]

Objects falling unimpeded under the influence of gravity have an acceleration (g) = 9.8m/s² with gravity acting about the center of mass.

? How many limb segments contribute to elevating the center of mass in the organism with sprawling posture?

? How many limb segments contribute to elevating the center of mass in the organism with erect posture?

Remembering that the organisms are of equal mass, which organism, sprawling or erect, will achieve a greater force in falling from a standing position? Why? [Hint: Think about the relative heights of the center of mass.]
? Under the constraints of this model, can one simultaneously increase stride length and decrease the height of the center of mass? If the requirement of equal limb segments is relaxed, how can you increase stride length in the sprawling posture without increasing the center of mass? What might constrain (limit) this “adaptation.”

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8) Human pelvic girdle sexual dimorphism (optional)

Like the shark, the pelvic girdle of humans is sexually dimorphic, although for different functions. Use the handout and workbook to determine the gender of the two os coxae on display.