1. **Primitive features of the axial skeleton of the cyclostome**

   The preserved lamprey skeleton at this station demonstrates the primitive design of the vertebrate axial skeleton. Notice that the notochord is persistent, large, and strong and vertebral centra are absent. Although rudimentary neural arch elements (2 pairs per body segment) are present along the entire length of the body, they are best developed in the anterior region of the trunk. Fin rays of dermal origin support the median fins. There are no ribs and the tail is of the protocercal type.

2. **Cross-section of the cyclostome**

   Identify the following structures: notochord, notochordal sheath, neural arch elements, and dorsal dermal fin ray support. Note that the neural arches abut upon the large notochord but do not meet above the spinal cord. Note: Neural arch elements are the tiny red structures visible on only one end of the specimen on slide.

3. **Persistent notochord**

   The trunk region of the sturgeon, a chondrostean (see Kardong, Figure 8.17a) shows the persistent notochord common to most groups of fishes except the teleosts. Here, a large notochord is retained into adulthood and is only partly replaced by the surrounding vertebral centrum. A large notochord was present in the earliest tetrapods as well, and is still fairly large in the order Urodela.

![Diagram](image-url)
4. Axial skeleton of the shark
Note that the skeleton is entirely cartilaginous. The vertebral column (as in other fishes) shows little regional differentiation - only trunk and caudal regions may be recognized. Study the vertebrae and identify the structures shown in Kardong, Figure 8.15d. The shark vertebral column is diplospondylous (i.e. there are two vertebrae per body segment) from the level where the hemal arches begin to the end of the tail. Some bony fishes (e.g. the holostean, Amia) are also diplospondylous. What is a possible functional advantage of this condition? The short, lateral ribs are the dorsal ribs. Pterygiophores, which are the elements between the vertebral spines associated with the median fins, tend to fuse into the plate-like cartilages.

5. Axial skeleton of the bony fish
The spine is well ossified in teleosts (contrast with sturgeon). Only trunk and caudal regions are present in the vertebral column. Identify the neural and hemal arches. Note the poorly formed zygapophyses. Both dorsal and ventral ribs are present. The ventral ribs are the larger ribs which surround the body cavity and fuse in the caudal region to form the hemal arches. In life, the shorter dorsal ribs lie in the connective tissue septum between the main dorsal (epaxial) and ventral (hypaxial) muscle masses of the trunk (see Kardong, Figure 8.6; see also Figure 8.17b and 8.17c at station 3); the dorsal ribs appear to be the homologues of tetrapod ribs. Note the pterygiophores supporting the median fins and their relationship to the fin spines and neural and hemal arches. Are the pterygiophores dermal or endochondral bone? The tail is of the homocercal type. Compare the external outline of tail to the internal structure using Kardong, Figure 8.20 on the next page at station 6.
6. Tail form in fishes
The protocercal tail is demonstrated by a cyclostome. It is generally considered to be the primitive type of tail. The hypocercal (a reversed heterocercal) tail may have been derived from the heterocercal tail or directly from the protocercal tail. Anaspid and pteraspids among the ostracoderms and a few other fish have this form of tail. Look at the heterocercal tail demonstrated here by a shark. This tail tends to depress the head and is common (but not confined) to fishes without an air bladder. Other fishes with heterocercal tails include cephalaspid, placoderms, some crossopterygians, and some dipnoans. The diphycercal tail is similar to the protocercal but is secondary rather than primitive. It is found among the xenacanthimorph sharks (pleuracanths), chimaeras, some sarcopterygians (coelacanths), and a few actinopterygians. A homocercal tail is symmetrical externally, but shows its derivation from the heterocercal tail form in the asymmetrical skeletal structures, as seen in Amia. Refer to Kardong, Figure 8.20.

![Diagram of fish tails](https://example.com/fish-tails-diagram)

**FIGURE 8.20** Caudal fins of fish. (a) Heterocercal sturgeon. (b) Diphycercal Polysterus. (c) Homocercal Amia. Note the positions of the vertebral column and the conditions of the remaining notochord. Sequence leading to the homocercal tail is shown to the right of each figure. After Kent.

7. Vertebral column of the anuran (tailless) amphibians
Frogs and toads possess rather specialized skeletons. There are single cervical and sacral vertebrae. The caudal vertebrae have fused to form a rod-like bone called the urostyle. There has been a considerable secondary reduction in the number of trunk vertebrae. The ribs have been lost and the transverse processes have become greatly elongated. Can you offer any functional explanations for these specialization.
8. **Skeleton of the Urodela/Caudata (tailed) amphibians**

Note the general fish-like similarity of the trunk and caudal vertebrae in this aquatic salamander (Necturus). The specimen displays the beginnings of the regional differentiation of the spinal column typical of tetrapods. The first vertebra is modified as a cervical vertebra. There is a single sacral vertebra joining the spine with the weak hind limbs and pelvic girdle. The centra are amphicoelous (see Kardong, Figure 8.4) and originate from both the notochordal sheath and surrounding perichordal mesenchyme. The cavities at the ends of the centra are filled in life with a gelatinous material derived from the notochord.

![General centra shapes](image)

**FIGURE 8.4 General centra shapes.** The shapes of articulating central ends, as viewed in sagittal section: (a) acoelous, both ends are flat; (b) amphicoelous, both ends are concave; (c) procoelous, anterior end is concave. Anterior is to the right;

9. **Vertebral column of a reptile (Crocodilian)**

The alligator pelvis illustrates the two strong sacral vertebrae typical of most reptilian subclasses. This number is secondarily increased in some advanced dinosaurs (Archosauria) and mammal-like reptiles (Synapsida). There is a distinct lumbar region in the alligator, but in most other reptiles the ribs there are generally present on all the trunk vertebrae (since reptiles have a single trunk cavity the vertebrae are referred to as trunk vertebrae rather than thoracic and lumbar). Note the large chevron bones (hemal arches) on the tail vertebrae. Notice also the presence of well-formed cervical ribs in the neck region. Identify the canal enclosed by the capitulum, tuberculum (which are the 2 heads of the ribs), and centrum is also seen in mammals (= transverse foramen). The anterior thoracic ribs have two heads (the primitive condition), while the posterior ribs have one.

10. **Vertebral column of the snake**

The vertebrae of snakes are numerous and show little regional differentiation. The absence of a sternum is secondary. Why is this specialization advantageous to the snake? The ribs of snakes have a single head, they retain only the capitulum.

The trunk vertebrae of snakes (and some lizards) have accessory articular facets on the neural arches in addition to the normal pre- and postzygapophyses. Articulate the python vertebrae to see the relationship between the zygosphene at the anterior end of the neural arch and the zygantrum at the rear of the arch (see Kardong, Figure 8.30). How are these accessory articulations related to the snake’s mode of locomotion? The strong projection from the ventral surface of the centrum is the hypapophysis; it serves principally as a site for muscle attachment. What is the form (refer to Kardong, Figure 8.4 above) of the centrum in the snake vertebra?

![Trunk vertebrae from a snake in anterior (a) and posterior (b) views. In addition to interlocking pre- and postzygapophyses, snakes have an additional set of processes, the zygosphene and zygantrum, that engage to further prevent wringing of the long serpentine vertebral column.](image)
11. Turtle carapace
The trunk vertebrae of turtles, as well as their expanded ribs, contribute to the formation of the carapace unique to this group of reptiles. Both the neural arches and the ribs fuse to the undersurface of large dermal plates; additional dermal elements lying between or opposite the rib ends complete the rim of the carapace. Enlarged epidermal scales or scutes overlay the dermal plates. The various components of the shell are still easily distinguished in the juvenile snapping turtle, but are less obvious in adult turtles. There are two sacral ribs as in other reptiles.

12. Axial skeleton of the birds
Birds have numerous cervical vertebrae with distinctive heterocoelous centra. Articulate the neck vertebrae of the turkey and determine which types of intervertebral movement are facilitated and restricted by centra of this shape. Cervical ribs are fused to the vertebrae in birds (compare with reptiles and mammals). The thorax is rather rigid. Some thoracic, all the lumbar and sacral and some caudal vertebrae fuse with the pelvic girdle to form a synsacrum. Why is this of advantage to the bird? How many vertebrae are included in the synsacra shown here? Notice the ossified tendons along the dorsal surface of the trunk.

The last caudal vertebrae fuse to form a blade-like pygostyle. What is its function? The process at the middle of each rib is the uncinate process. What is its function? The segment between the sternum and true rib is generally ossified in birds but is not ossified in reptiles and mammals. Note the large sternum with a pronounced keel. What muscles originate from this keel? Also note the uncinate processes on the lateral aspect of the ribs. These are thought to be associated with the maintenance the integrity of the body cavity during flight.

13. Mammalian atlas-axis complex
In mammals (and most reptiles), the axis (second cervical vertebra) has incorporated part of the centrum of the atlas vertebra. In adult mammals (in contrast to reptiles), this pleurocentrum is fully fused with the axis and forms a small part of the anterior half of its centrum. The odontoid process or dens is a new (neomorphic) structure added to the front of the mammalian axis vertebra. It arises as a separate ossification center from that of the atlas pleurocentrum and later fuses with it. The mammalian axis centrum therefore consists of three distinct components. Manipulate the atlas-axis complex of the bison to determine what types of movement it permits.

14. Additional features of mammalian vertebrae
The lumbar vertebra of the dog illustrates the acoelous centrum, which is typical of the thoracic and lumbar vertebrae of mammals. The cervical vertebra shows a very slight opisthocoelous type of centrum frequently present in the posterior region of the neck. Notice the stout, short transverse processes characteristic of mammalian cervical vertebrae. These processes represent, in part, fused cervical ribs. Note also the transverse foramen, which, in life, transmits the vertebral artery and vertebral venous plexus, as well as a branches from the sympathetic nervous system. This foramen is diagnostic of mammalian cervical vertebrae, but is sometimes absent from the last cervical vertebra. With the exception of the three-toed sloths (with 8 or 9) and the sea cow and two-toed sloth (both with 6) all mammals have 7 cervical vertebrae.

FIGURE 8.4 General centra shapes. The shapes of articulating central ends, as viewed in sagittal section: (e) heterocoelous, saddlelike articulating ends. Anterior is to the right.

FIGURE 8.4 General centra shapes. The shapes of articulating central ends, as viewed in sagittal section: (a) acoelous, both ends are flat; (d) opisthocoelous, posterior end is concave. Anterior is to the right.
15. Vertebral epiphyses and intervertebral discs
Developing mammalian centra differ from those of other tetrapod classes in the possession of bony epiphyses. These plates typically become completely fused with the main body of the centrum in adult terrestrial mammals. A cushion or pad of dense fibrocartilage, the intervertebral disc, is present between the centra of adjacent vertebrae and is particularly well developed in the posterior thoracic and lumbar regions. Locate these discs in the lumbar region of the monkey shown here. The peripheral portions of the intervertebral discs are probably formed of the remains of the intercentra, while the central portions of the discs, which are gelatinous in juvenile mammals, are derived from the notochord.

16. Caudal vertebrae in mammals
The tail vertebrae of mammals vary greatly in number and relative development. In the porcupine, which has a strong tail, the individual vertebrae are large, rugged, and have prominent transverse processes and chevron bones. With what structures in the bony fishes are the chevron bones homologous? Compare with the caudal skeleton of the cat. The three or four caudal vertebrae in humans are normally fused to form a single bone, the coccyx.

17. Girdles and fin skeletons of the bony fish
The pectoral girdle of bony fish consists of two elements which arose by way of endochondral bone formation, the scapula and coracoid. These articulate distally with the radials, which are bones in the proximal pectoral fin. The scapula (dorsal) and coracoid (ventral) also articulate with the posterior aspect of large bone of dermal origin called the cleithrum. A variable number of additional dermal bones link the upper aspect of the cleithrum to the posterior aspect of the cranium. Therefore, the pectoral fin is securely attached to the head via the pectoral girdle (examine the specimen of Amia to see this).

The pelvic girdle consists of a single bone on each side which articulate with one another in the midline but does not connect to the vertebral column. The radials of the pelvic fin are reduced to a few short bones nearly hidden under the fin rays.

The fin rays in both pectoral and pelvic fins (called lepidotrichia) are also of dermal origin and are branched and jointed at their proximal end. Compare to the fin rays of the shark (see laminated illustration of Kardong, Figure 9.10).

18. Cranial bones and dermal scales
The superficial bones of the vertebrate skull and shoulder skeleton are derived from modified dermal scales or armor. The continuity of scales and cranial bones is easily seen at the posterior aspect of this sturgeon skull. Fin rays are also formed from fused dermal scales.
19. Limb girdles of the frog

Compare the shoulder skeleton of the bullfrog to Kardong, Figure 9.19m. Frogs and toads are the only modern tetrapods to retain the dermal cleithrum. Locate the scapula, anterior coracoid (sometimes called the procoracoid), and clavicle. Note the large suprascapular cartilage in this specimen. This cartilage is also present in many reptiles (compare with the iguana at station 7). How is the frog shoulder different from that of a labyrinthodont, such as the one shown in Kardong, Figure 9.19k?

The greatly elongated ilium of the frog is characteristic of the modern anurans and is functionally related to the jumping habit of these animals. Identify the ilium, ischium, and pubis of the frog pelvis. Note that the pubic region of the pelvic girdle is calcified cartilage, not bone. A characteristic feature of Lissamphibia is the failure of the pubic element to undergo ossification. The limb girdles of urodeles are generally small, degenerate and poorly ossified.

Note that two elongated tarsal bones add an extra segment to the anuran hind limb. What is the advantage of this?

20. Limb girdles of the lizard

Use Kardong, Figure 9.19g (Sphenodon – closely related to lizards) to identify the scapula, anterior coracoid, clavicle, and interclavicle. Notice the well-formed suprascapular cartilage and the broad sternum of calcified cartilage. Note also the relationships of the ribs to the sternum. Compare the lizard with the crocodile. In what ways is the lizard shoulder more advanced than that of the frog, but less advanced than those of mammals?

Identify the structures on the iguana pelvis shown in Kardong, Figure 9.21e. Note that the pubic and ischial elements do not connect to one another resulting in a distinctive notch called the puboischiatic (or thyroid) fenestra. The prominent process on the front edge of the ilium is for the attachment of the large dorsal trunk muscles, which are important in the locomotor movements of reptiles. Locate the obturator foramen. How does it compare in development with that of mammals and birds?

21. Limb girdles of the bird

This specimen is the forelimb girdle of a flamingo. The furculum (a.k.a. the wish bone) is made up of two clavicles joined ventrally by the interclavicle. Note that the scapula does not have a spine. The bone that is usually called the coracoid is the homologue of the reptilian anterior coracoid (procoracoid).

The pelvic girdle is securely attached and is usually fused with the synsacrum. The ilium is the largest component of the girdle, extending both anterior and posterior to the acetabulum and is sometimes so completely fused with the ischium that they appear to be a single element. The pubic bones are the thin, sliver-like bones on the ventrolateral aspect of the girdle and they do not join at the midline.

This bird pelvis is from a turkey (compare with Kardong, Figure 9.21i). What features characterize the pelvic girdle of this tetrapod group? How does the bird pelvis differ from that of the crocodilians (Figure 9.21f)? Examine the illustrations of the ornithischian (“bird hip”) dinosaur pelvises in Kardong, Figure 9.21g. Similarities in pelvic structure are seen in the bird and ornithischian dinosaur; this is a case of convergence.
22. Pectoral girdle of the monotreme
The spiny echidna shoulder girdle illustrates the type of girdle that was primitive for archosaurs and their descendants (birds), as well as mammal-like reptiles. The anterior border of the scapula has not yet turned outward to produce a spine. Compare with Kardong, Figure 9.19d. Find the scapula, clavicle, anterior and posterior coracoids, and interclavicle.

23. The mammalian clavicle
The clavicle is the only remaining dermal element in the therian shoulder girdle. It may be well developed as in the opossum, man, and other primates; small and floating, as in the cat; or entirely absent, as in many running ungulates (deer, antelope, etc.). How do you account for the difference between phyla?

24. Ribs and sternum of mammals
This thoracic cage from a young opossum illustrates the general organization of the ribs and sternum in mammals. Note the costal cartilages, which extend the bony ribs. There are two heads on the anterior ribs but a single head on the posterior ribs. The last or floating ribs do not join the sternum. The mammalian sternum is typically composed of a series of bony segments called sternebrae. The most anterior of these is called the manubrium and the last or most posterior is the xiphisternum. The latter may be extended piece of cartilage called the xyphoid cartilage.

25. Pelvic girdle of young mammal
This pelvis from a juvenile sea lion clearly shows the three bones that will ultimately fuse to form the composite bone of the adult. What is the name of this composite structure? Note also the separate portions of the vertebrae that are not fused in this specimen.

26. Epipubic bones
The pelvis of the opossum displays the prominent epipubic or marsupial bones common to both monotremes and metatherian mammals and are present in both sexes. Epipubic bones are apparently primitive for mammals but have been lost in placental mammals. They are not known in mammal-like reptiles and their reptilian homologue, if any, is uncertain.
27. Baculum
An os penis bone (or baculum) is present in the male reproductive organ and is only found in a few groups of placental mammals (e.g., soricomorpha, chiroptera, rodentia, carnivora, and most non-human primates). Its counterpart, the os clitoris, is occasionally found in the females of these same groups. The baculum may help to stiffen the penis, but its mechanical function is largely unknown.

There is no baculum in either monotremes or marsupials. It has been suggested that the baculum may be derived from fused epipubic bones yet there is very little evidence to support this suggestion.

28. Epiphyses
Bony caps or epiphyses do not occur at the ends of growing endochondral bones in fishes or amphibians. In reptiles, they are usually poorly formed when present. The epiphyses at the ends of the long bones (limb bones) of birds tend to remain cartilaginous or to fuse with the shaft (diaphysis) at an early age.
Bony epiphyses are retained at the ends of mammalian long bones (and some other bones) until lengthening is completed. Examples illustrated here are appendicular bones from young deer and adult sea lions. Notice the incomplete fusion of the epiphyses to the diaphysis in the adult sea lion. Complete fusion of epiphyses is rare in many marine mammals and never occurs in many cetaceans. How do you account for this?

29. Forelimb skeleton of the bird
Only 3 digits appear to be retained in at the distal ends of the wing in modern birds. The fused metacarpals of these digits, together with some carpals comprise the carpometacarpus. How many phalanges are retained in these digits? Two carpals are normally present in the wrist joint (Kardong, Figure 9.24e). Identify the humerus, radius, and ulna on this wing skeleton.

30. Hind limb skeleton of the bird
In modern birds, metatarsals 2, 3, and 4, plus some tarsal bones unite to form the tarsometatarsus. Other tarsals fuse with the distal end of the tibia to produce the tibiotarsus. Notice the reduced fibula on the pigeon skeleton. These modifications in birds indicate either a running or hopping ancestry. Also notice that, on both the distal hind limb of the eagle and pigeon hind limb, the first digit turns rearward and acts as a prop (other toes may do likewise). See Kardong, Figure 9.25c.

31. Hollow long bones of birds
This sectioned femur of a golden eagle demonstrates the hollow nature of the long bones of many flying birds. In life, an air sac fills much of this space.
32. Variation in mammalian foot structure
The foot skeleton of the porcupine represents the primitive, generalized plan for therian mammals. Contrast this with the foot skeleton of the fawn, in which the elongated metatarsals (3 and 4) have fused to form a single bone often called a metapodial or cannon bone. Remnants of digits 2 and 5 may also be retained, as seen on the front foot skeleton of the adult deer. How can you account for the reduction of toes and the fusion of metapodial bones in running mammals?

The stance of the porcupine foot is plantigrade, meaning that the carpal and tarsal bones are normally in contact with the ground. This stance is primitive to mammals (and is retained in humans). At the opposite extreme, is the unguligrade posture (e.g. the deer), in which only the terminal phalanges rest on the ground. The digitigrade stance (e.g. dog) is intermediate; the distal and proximal phalanges tend to rest on the ground, but not the carpals or tarsals. Which toe has been reduced or lost in the hind foot of the dog?

33. Mammalian appendicular bones and landmarks
Use the labeled illustrations at this station to identify the bolded bony landmarks on the fore and hind limb bones of a mountain lion.