

Vertebrate Structure & Adaptation

Biology 6A / Sanhita Datta
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As we have examined in a previous lab, one of the major keys to the success of vertebrate animals is the power, speed and agility resulting from having an articulated, bony endoskeleton. We can learn much about the correlation of body form and function by studying the basic structure of the vertebrate skeleton and some of the many derivations adapted to specific life histories.

Bone provides support and movement via attachments for soft tissue and muscle. It protects vital organs, and plays a role in the metabolism of minerals such as calcium and phosphorus. The inorganic components of bone (largely calcium-phosphate hydroxylapatite crystals) comprise 60% of its dry weight and provide the compressive strength of bone. The organic component is primarily collagen, which gives bone great tensile strength.

We will examine some details of the mammalian skeleton using our own large-brained, bipedal human structure, along with the more typically quadrupedal cat. We will then look at some functional variations in form displayed by a variety of mammalian skeletal parts. Thirdly, we will study the specializations of the tetrapod skeleton for flight as demonstrated by an assortment of birds.


Development & Structure of Bone


In mammals, there are two basic structural types of bone. **Compact bone** forms the outer shell of all bones and also the shafts in long bones. **Spongy bone** is found at the expanded heads of long bones and fills most irregular bones. Spongy bone also may contain marrow — yellow marrow for fat storage, or red marrow for the production of blood cells.

Bone formation, or **ossification**, begins with an aggregation of embryonic **mesenchymal** cells (nonspecialized connective tissue in the mesoderm). These cells then develop into either **fibroblasts** that will lay down the collagen matrix, or **osteoblasts** to form bone cells. Specific bones are typically classified by their type of ossification:

With **intramembranous** bone formation, also called dermal bone, ossification occurs within the developing dermis of the mesoderm. This process gives rise to the bones of the lower jaw, the paired bone plates forming the roof of the skull, and the clavicle of the pectoral girdle. It also produces dentin within teeth and other bone that develops in the skin, such as the scutes of turtles and crocodiles.

Endochondral [“within cartilage”] bone formation, also called replacement bone, is the process by which bone is deposited within pre-existing cartilage skeletal elements. This is the mechanism that forms the majority of bones in the tetrapod skeleton.

 Examine the prepared slides of both compact and spongy bone. Recognize the similarities and differences between the two types. Recall that bone is a type of living tissue. Identify the **lacuna** spaces for the **osteocytes**, and the **central canals** allowing penetration for blood vessels and nerves.

 Observe the longitudinal sectioned human long bone with a dissecting scope. Identify the location of both compact and spongy bone. How does their form & location relate to their respective functions?

The tetrapod skeleton can be subdivided into two major regions:

- I. The **axial skeleton** includes the skull and vertebral column along with the attached rib cage. Also included is the **visceral skeleton** with structures derived from the pharyngeal arches, but located in the throat region rather than in the skull. These are the bony and cartilaginous


components of the hyoid apparatus and larynx that provide attachment for the muscles of the tongue, pharynx, and voicebox, and the tracheal rings that keep the airway open.


II. The **appendicular skeleton** includes the pectoral girdle with its associated forelimbs, and the pelvic girdle with the hind limbs.

Some terms used to describe bone structure:

- A **process** is a projection or spine extending from the surface of a bone to increase the surface area for muscle attachment. Larger processes imply larger, more powerful muscles. A ridge-like process may be called a **crest**. Two processes can fuse to form an **arch**.
- A **foramen** is a hole in a bone, usually to allow the penetration of nerves and blood vessels. The most conspicuous is the *foramen magnum*, the hole in the back of the skull allowing the spinal cord to extend from the brain down the vertebral column.
- A **joint** is a connection between bones. A **suture** is a fixed joint, such as between the plates forming the cranium. A **symphysis** is a joint with limited flexibility, such as the connection between the two halves of the jaw or pubis. The connection between bones at a suture or symphysis is made by connective tissue for membrane bone and by cartilage for replacement bone. A **diathrosis** is a freely movable joint. It is generally characterized by a **condyle** (swelling or protrusion) on one bone that fits smoothly into the **fossa** (pocket or groove) of the second bone. Each articulating surface is lubricated by an extremely smooth layer of hyaline cartilage, and the two units are held together by dense connective tissue **ligaments**. Diathroses come in many variations, but they can be classified into three functional groups.
 - A **hinge joint**, with a cylindrical condyle turning in a grooved fossa, limits motion primarily to a single plane. Example: mandible to skull.
 - A **ball-and-socket joint**, with a hemispherical condyle and nearly congruous fossa, allows movement and rotation in many directions. Examples: shoulder and hip joints.
 - A **pivot joint**, with a disk-shaped condyle in a notch-like fossa, restricts motion to rotation around the long axis of the bone. Example: radius pivots on the ulna as the wrist is rotated.

See **Campbell, Figure 49.26**.

 Examine a human skeleton. Observe the overall layout of the axial, visceral, and appendicular skeleton. Locate examples of a **suture** joint, a **symphysis**, and the three types of **diathroses**. For each diathrosis, identify its **fossa** and **condyle**. Demonstrate the range of motion for each of these joints in your own body.

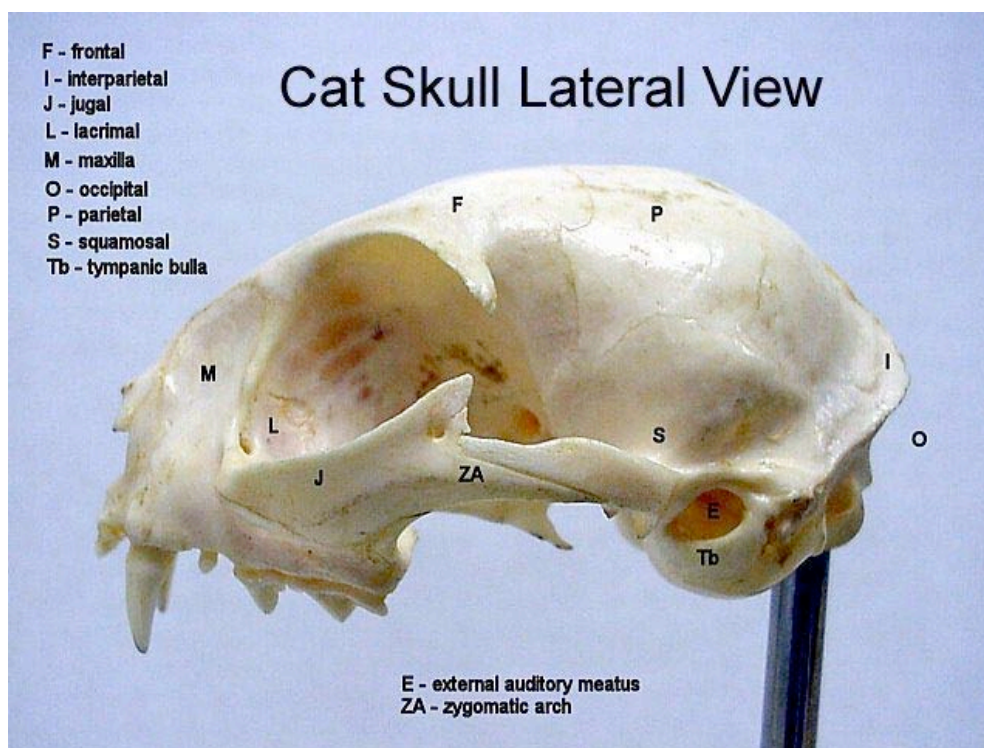
 Examine the cat skeleton. Locate the corresponding skeletal components described above for the human skeleton in the cat.

Ia. Axial Skeleton — skull

The **skull** is constructed of the **cranium** (braincase), **facial bones**, and **mandible** (lower jaw).

Cranium. The base of the cranium is the occipital bone that forms around the foramen magnum. Here the skull articulates with the first cervical vertebra by means of one (reptiles & birds) or two (amphibians & mammals) **occipital condyles**. The roof of the cranium is constructed of the pairs of frontal and parietal (top) dermal bones. A transverse **nuchal crest** may form at the margin of the parietal and occipital bones for enhance attachment of neck muscles in animals with massive heads or in carnivores that use twisting head movements to tear flesh from their prey. A medial **sagittal crest** may appear on the top of the skull between the parietal bones to anchor large chewing muscles in some carnivores and to increase the apparent size of the head for intraspecific displays. The lateral and lower walls of the cranium are composed of the temporal bones which include the auditory bullae and the **mandibular fossa** for articulation with the lower jaw.

Facial bones. The jugals are the main cheek bones, forming the lower margin of the orbits (eye sockets). The size and position of the orbits is informative regarding the visual behavior of the animal. A posteriorly-directed process from the jugal on each side joins with a process from the temporal bones to form the **zygomatic arches**. The zygomatic arches provide attachment surfaces for the masseter muscles from the mandible. The space under the arches allows movement of the mandibular processes and passage of the temporal chewing muscles from the mandible to the surface of the cranium. The facial bones anterior to the jugals form the **rostrum** (snout). The nasal bones extend from the frontal bones to the nostrils. The premaxillae continue from the nostrils to the front of the mouth, and are the bones bearing the incisor teeth. The lateral walls of the rostrum are the maxillae, and these bones bear the canines and cheek teeth of the upper jaw. The palatine bone, along with the margins of the maxillae and premaxillae, form the **hard palate** that separates the oral passages from the nasal passages. This innovation found in mammals, birds, and crocodylian reptiles, allows the animals to continue to breathe when they have food in their mouths. (Snakes and lizards must hold their breath!)



Mandible. Whereas in all other vertebrates, several bones articulate to form the mandible, in mammals it forms from just a pair of **dentary bones**. The joint between the dentaries may be a flexible symphysis in most tetrapods, but in many mammals they fuse completely to form a more sturdy biting structure. The **mandibular condyle** protrudes from the **condyloid process** at the rear of each dentary. Superior to the position of the condyloid is the **coronoid process**, projecting up under the zygomatic arch and providing lever-action and large surface for muscle attachment to close the jaw. It is particularly prominent in carnivores with powerful biting action. Inferior to the condyloid is the **angular process**, which provides attachment surface for muscles that pull the mandible from side to side in grinding action. It is most developed in certain herbivores.

Teeth. The most telling characteristic of an animal's trophic behavior is displayed by its teeth. They are also often diagnostic of the different mammalian orders. Most mammals are **heterodont**, having a variety of different types of teeth.

- The typical numbers stated refer to the set of teeth on each side of both upper and lower jaws.
- ▶ **Incisors** are the front-most teeth, typically specialized for clipping, nipping, or scraping. Most mammals have three incisors per set.

- ▶ **Canines** are adjacent to the incisors, cylindrical and pointed for grasping and piercing. Or they may be enlarged to form tusks for digging and intraspecific displays. Only one per set, or absent.
- ▶ **Cheek teeth** are the most variable, but generally they are for chewing. They may be blade-like for shearing of meat, or blunted with rounded cusps for grinding plant matter. Numbers are also highly variable, but most typically 2–4 **premolars** and 3–4 **molars** per set.

Incisors, canines, and premolars are deciduous in mammals, i.e., a first set of “baby teeth” erupts and then are replaced by permanent sets. Molars erupt after the permanent set of teeth appears.

Identify the above structures in bold in the skull of the cat. Compare the descriptions to your observations. Use your dissecting microscope to observe details, especially of the joints and teeth. See

Repeat the above identifications using the human skull.

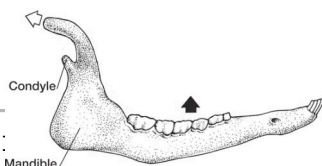
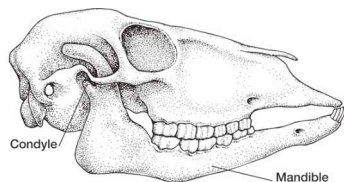
Examine the skulls of the other specimens representing six of the 21 orders of mammals. Use the dissecting microscope for smaller skulls. Identify specific adaptations and correlate them to the life history of that order. Observe fine details of the variations of species within the same order. See Campbell, fig. 34.36 for more on the orders of mammals.

- ❖ order: **Carnivora** (cats, dogs, weasels) Often with prominent nuchal crest to support muscle for shaking and tearing prey. Some also with conspicuous sagittal crest for attachment of jaw muscles and enlarging apparent head size, esp. in males. Often with long nasal tracts. Mandibles w/ large coronoid process. Long canines; slicing molars; last upper premolar overlaps first lower molar → shearing action. Tight fit of mandibular hinge joint restricts sideways motion of lower jaw.
- ❖ order: **Primates** (humans, apes, monkeys) Short rostrum; orbits directed forward (↓ olfaction / ↑ vision). Enlarged parietal bones → large brain case. Flat molars w/ rounded cusps (omnivorous).
- ❖ order: **Rodentia** (mice, rats [$>40\%$ of mamm spp.]) Long incisors w/ enamel only on forward surface → continuous growth & sharpening. No canines (gap between incisors & cheek teeth). Molars w/ circular ridges for grinding. Large angular process on mandible.
- ❖ order: **Insectivora** (moles, shrews) Skull small w/ reduced orbits & auditory bullae. Rostrum long & slender. Incisors & canines variable; cheek teeth with sharp cusps for grabbing invertebrate prey.
- ❖ order: **Artiodactyla** (cows, sheep, pigs, and deer) Very large nuchal crest and transverse process to support massive head. Wide incisors; canines absent (gap) or enlarged as tusks (in pigs); cheek teeth w/ parallel ridges to ↑ grinding surface. Thin coronoid process but broad angular process on mandible. Mandibular fossa fits loosely over mandibular condyle to allow lateral motion of lower jaw.
- ❖ order: **Cetacea** (dolphin) ↓ nasal bones / ↑ premaxillae & maxillae bones → “telescoped” skull w/ very long rostrum and nostrils displaced to top of head (blow hole). Skull often asymmetrical. Dentition usually homodont w/ uniform spiky teeth for grabbing swimming prey.

Note: Campbell shows that the Artiodactyla and Cetacea are now considered to be a single order, the Cetartiodactyla, because they are closely related. However, their skulls look very different.

Take the **Skull Quiz!** Use the descriptions above to identify the unlabeled skulls to their respective mammalian order. Mark your answers on a Scantron and turn it in before you leave. You may work in groups of two or three.

Sheep skull

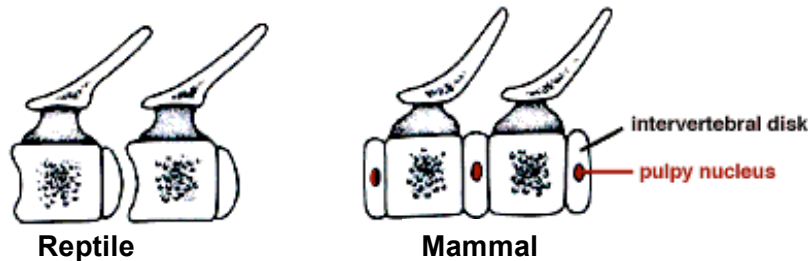


Bruce Heyer 12/:



Ib. Axial Skeleton — vertebrae

A series of **vertebrae** comprise the **vertebral column**. Each vertebra consists of a centrum and one or two arches, plus various processes. The **centrum** formed around the embryonic notochord, eventually replacing it. In mammals, the two faces of the centrum are flat, and separated from the face of adjacent vertebrae by elastic **intervertebral disks** to absorb compressive forces. In amphibians and reptiles, the faces are concave on one side and convex on the other to allow flexion with lateral body undulations.



Dorsal to the centrum is the **neural arch** that encloses the **spinal cord**, usually topped by a **neural spine** (spinous process). Lateral projections off the base of the neural arch form the **transverse processes** — the most common spinal processes. The transverse and neural spines provide increased attachment surface for the muscles of the trunk, neck, shoulders, and forelimbs. On the forward face of the neural arch are the upward-facing **anterior facets** that articulate with the downward facing **posterior facets** on the neural arch of the preceding vertebra. These facet joints limit flexion of the spine in mammals to mostly the dorsoventral axis. Vertebrae of the trunk may have additional lateral facets for joining with ribs. In fishes and some tetrapods with large tails, the caudal vertebrae may also feature a ventral (hemal) arch protecting major blood vessels, and a hemal spine.



The vertebral column is divided into regions:

Cervical (neck) region. Only one cervical vertebra in amphibians, thus limiting head movement. Usually seven in reptiles and mammals. Often compressed and/or fused in fossorial, saltatorial, and aquatic mammals (see below). There is a variable number of cervical vertebrae in birds (as many as 25 in swans), since the neck region is the only flexible region of the avian spine.

Trunk region — in amniotes, the anterior **thoracic** (chest) region has 12–15 vertebrae with ribs and large neural spines (except in bats). In ungulates, they also have large transverse spines to anchor the neck muscles supporting the large head. The posterior trunk **lumbar** (abdominal) region usually has 6–7 vertebrae with large transverse spines and lacking ribs (except in snakes). The absence of abdominal ribs allows greater dorso-flexion, especially in mammals. This flexion is important to increased speed in cursorial animals (see below). Whales elongate their bodies by adding more lumbar vertebrae, as many as 20, to this flexing region of their trunk.

Sacrum — fused sacral vertebrae to brace the pelvic girdle. One sacral vertebra in amphibians, two in reptiles and most birds, three to five in most mammals.

Caudal region. Highly variable in number. Fishes and some large-tailed tetrapods have prominent caudal vertebrae with hemal arches and spines (chevrons). But most tetrapods show reduction of arches and processes in the caudal vertebrae progressing to simple cylindrical centra toward the terminus of the tail. In humans, the four caudal vertebrae are reduced and fused to form the coccyx.

- 📖 Use your dissecting microscope to observe the fine structure of the human vertebrae. Identify from which region of the vertebral column they came.
- 📖 Examine the articulated vertebral columns of the cat, the monkey, and the human. Identify the specific regions.
- 📖 Note the differences between the similarly sized cat and monkey and relate these differences to their respective life histories.
- 📖 Note the differences between the quadrupedal monkey or cat and the bipedal human spinal columns. Relate the specific differences related to the adoption of an upright body.

II. Appendicular Skeleton

In bony fishes, the girdle supporting the pectoral fins articulates directly with the skull, limiting head motion. In tetrapods, the pectoral girdle is independent of the skull and connects only indirectly with the axial skeleton.

The **scapula** bears the socket fossa for connection to the forelimb. In amphibians, reptiles, and birds, the scapula is anchored securely to the anterior end of the sternum by both the **coracoid** bone and **clavicle** — thus a scapula/coracoid/clavicle “tripod” stabilizes the head of the forelimb. However, since the scapula is held so close to the axial skeleton, for the forelimb to extend around the trunk the humerus (upper arm) of amphibians and reptiles must project perpendicular to the body axis and the forearm is splayed weakly at their sides. Hence amphibians and reptiles use their forelimbs mostly for perching and grasping, and rely upon their hind limbs and full body undulations for rapid locomotion. In birds of course, the “tripod” stabilizes the base of the wing.

Mammals demonstrate a significant modification of the **pectoral girdle**. The coracoid is eliminated and just the **clavicle** (collar bone) keeps a flexible connection of the scapula to the head of the sternum. The **scapula** is greatly enlarged and broadened to form a plate (shoulder blade) that allows the scapula to be held in place by muscle attachments rather than by direct articulation with other skeletal elements. Thus the whole girdle is more flexible and the shoulder socket can be positioned away from the midline. In turn, the lateral displacement of the shoulder socket allows the humerus (upper arm) to pivot parallel to the sagittal plane of the body, allowing greater range of motion and more rapid and powerful strokes of the forelimb.

The pelvic fins of fishes do not articulate at all with the axial skeleton. Conversely, the **pelvic girdle** of tetrapods generally fuses solidly with the sacrum of the vertebral column to brace the action of the hind limbs. The girdle is expanded in mammals (and in birds) to move the hip socket away from the midline for the same benefits described for the mammalian pectoral girdle. The ventral **pubic symphysis** of the pelvic girdle is generally more flexible in females to facilitate egg laying or live birth.

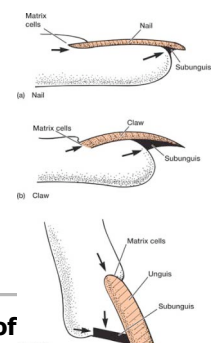
The forelimb and hindlimb are usually very similar in structure with a series of bones extending from the girdle to the distal ends:

Forelimb: humerus (upper arm) > paired **radius & ulna** (forearm) > usually three parallel series of **carpals** (wrist) > usually five parallel series of **metacarpals** (palm) > **phalanges** (digits/fingers).

Hindlimb: femur (thigh) > paired **tibia & fibula** (shank) > usually three parallel series of **tarsals** (ankle) > usually five parallel series of **metatarsals** (instep) > **phalanges** (digits/toes).

At the tip of the digits are usually found nails, claws, or hooves. These structures are derived from the skin and are composed of the protein keratin, not bone.

Some tetrapods lack hindlimbs, having only forelimbs: cetaceans; sirenid mammals (manatees); sirenid amphibians. And some tetrapods lack all limbs: snakes; legless lizards; caecilian amphibians.



Locate the above structures from the human appendicular skeleton and their respective positions in your body.

Locomotory Specializations in Mammals

Limbs are drastically modified to different ends in various groups of mammals. Here, we are concerned primarily with modifications that affect how an animal runs.

Several terms describe how and where an animal moves. **Aquatic** animals swim. **Volant** animals fly. **Cursorial** animals (cursors) run rapidly and for long distances. **Arboreal** animals are climbers, spending most of their lives in the trees. **Saltatorial** animals are hoppers. **Fossorial** forms are diggers, usually living in burrows.

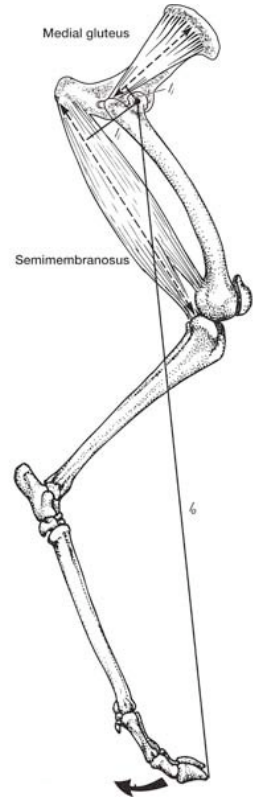
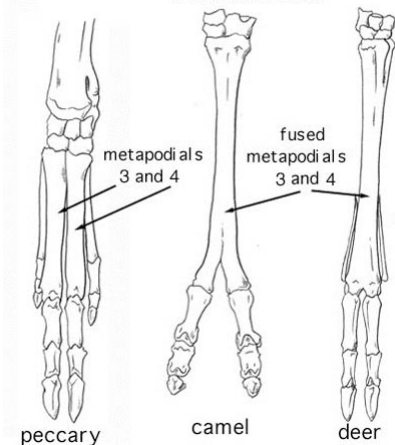
A full cycle of motion of a running or walking tetrapod is called a **stride**. An animal's speed is the product of its stride length multiplied times its stride rate. So there are two ways of increasing the speed of running: increasing stride length and/or increasing stride rate. Some animals are clearly specialized to increase speed through increasing stride length; the giraffe is an extreme example. Others move rapidly by having a very fast stride rate, for example in shrews and voles.

Increasing Stride Length

1. One way to increase stride length is to run on the tips of the toes. We recognize three basic patterns.

- ▶ **Plantigrade** species are those that place the full length of their foot on the ground during each stride. Humans, shrews, squirrels, and bears are examples, along with most reptiles and amphibians.
- ▶ **Digitigrade** species walk with most of the length of their digits, but not the soles of their feet, in contact with the ground. Dogs and cats are examples.
- ▶ **Unguligrade** species walk on their tiptoes, often on hooves. Deer and horses are examples.

2. A second way of increasing stride length is to lengthen limb elements. A common way to do this, found in several groups, is to have fewer but longer metapodials (metacarpals and metatarsals). Cursorial carnivores such as wolves and cheetahs have metapodials that are very long compared to their digits. The extreme cases of elongation are seen in the ungulate orders, Perissodactyla and Artiodactyla. Among the much more diverse artiodactyls, pigs and hippos have moderately long metapodials, which are unfused. The third and fourth metapodials, however, are larger than the others and bear most of the weight. Fusion of metapodials is complete in cows and deer, and the resulting bone is called a **canon bone**. Other digits are much reduced or lost.



3. A third and very common means of lengthening stride is to include the scapula as part of the limb, allowing it to swing forward and back with each stride. In cursorial mammals that use their scapulae in this fashion, the clavicle (which would restrict the movement of the scapula) is much reduced or lost. It is easy to watch the scapula in a cat move with each stride as the animal walks or runs.

4. Another way of lengthening the stride involves flexing the spine. This is associated with a bounding or galloping form of locomotion. When the animal pushes off with its hind feet, it extends its back. Contact with the ground by the hind legs prevents the rear part of the animal from moving backward, and the

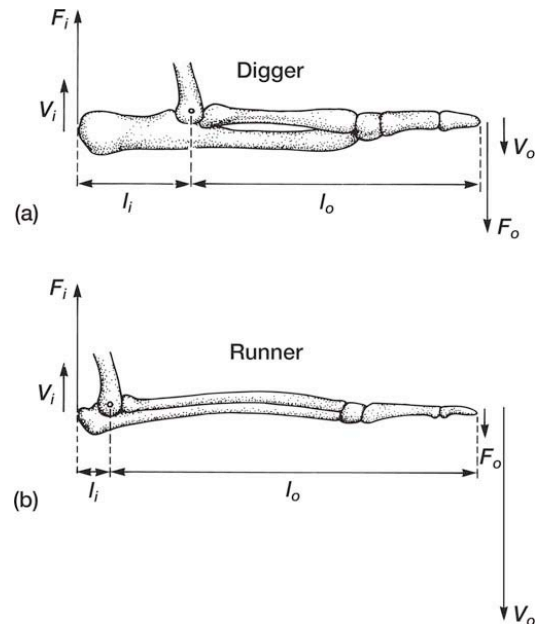
increase in body length becomes part of the forward stride. My old Professor Hildebrand at UC Davis calculated that cheetahs are so good at this movement that they could run nearly 10 km/hr without any legs at all!

5. Yet another means of lengthening the stride is to increase the distance traveled by the animal when its feet are off of the ground. This is determined by the animal's gait, or the sequence and manner by which it moves its feet when running. Weakly cursorial animals generally keep at least one foot on the ground most of the time; highly developed cursors have extended unsupported periods; and the feet of saltatorial animals may be off the ground for more than half of the stride.

6. A final means of lengthening the stride has to do with the mechanics of muscle action. A muscle can move a joint through a wider angle the closer it inserts to the joint.


Increasing Stride Rate

1. Muscles acting on bones behave as simple force-and-lever systems. Muscles inserted close to joints not only move the joint through a wider angle, but they make the bones on which they insert move faster. In doing so, however, they must exert more force than a muscle inserted farther away from the joint. We expect the muscles of fast runners to be inserted near the joint, while the muscles of animals that require considerable power (diggers, climbers, etc.) to be inserted farther away. We might also expect that bony processes to which major limb muscles attach (such as the elbow of a digger) might be longer in animals requiring more power, as this would increase the mechanical advantage of the muscle as it contracts. Because of the effort required to move their limbs, some large cursors have pairs of muscles that appear to act almost like the gearshift of a car; one muscle, inserted away from the joint, gets the limb moving; a second muscle inserted closer in, then takes over and moves the limb rapidly.



2. A bullet fired from a stationary rifle moves at the velocity imparted by the shell. A bullet fired from a speeding jet moves at the velocity imparted by the shell plus the velocity of the airplane. Similarly, the end of the femur moves at the velocity given it by the thigh muscles. The end of the tibia moves at the velocity given it by its muscles, plus the velocity of the end of the femur. One way of increasing speed is by adding parts, each moving at its own velocity. The overall velocity is then determined by the sum of the velocities of the parts. Adding motion by the scapula, and adding the metapodial and toe joints as moving parts (through adopting a digitigrade stance), accomplishes this.

3. The effort required to move a limb is a function of its mass and the distance of its center of gravity from the joint. The greater that distance, the greater the effort. The ulna of cursors typically is reduced or fused to the radius, and the fibula to the tibia. The number of digits is also reduced, concentrating the weight on one or two and decreasing the mass of the foot (this also moves the center of gravity of the limb closer to the body). The mass of muscle at the end of the legs is also reduced by simplifying the motion of the joints so that almost all motion is forward and backward, and by strengthening the joint for motion in that plane by changes in the bony articulation of its components and their ligamentous support (rather than strengthening by adding muscle mass).

 Examine the articulated axial and appendicular skeletons of the **cursorial/digitigrade** cat, the **arboreal/plantigrade** monkey, the **bipedal/plantigrade** human, and the **fossorial/plantigrade** mole. Identify the described specific parts of the appendicular structures in each of these specimens. Compare the special modifications of the skeletons of these specimens in relation to their respective life histories.

Flight Specializations in Birds

In specializing to an aerial lifestyle, birds are masters of packing a lot of power into a lightweight, rigid structure with a tight center of mass. Many of these specializations of the tetrapod body plan include:

Broadened pelvic girdle to allow bipedal posture ⇒ forelimbs free to be wings.

Feathers! ⇒ flat structures for excellent aerodynamic lift without the weight of other tissues.

Thin-walled, hollow, spongy bones ⇒ very strong, yet very lightweight.

Reduced mass of skull, jaw, legs, & tail ⇒ reduce weight and shift center of gravity.

Sacrum fused with lumbar vertebrae, last thoracic, and first caudal vertebrae to form **synsacrum** ⇒ rigid axial skeleton (other than neck).

Overlapping **uncinate processes** on ribs ⇒ reinforce thoracic wall.

Clavicle fused to form elastic **furcula** (wishbone) ⇒ anchor flight muscles, prevent chest compression, and recoil spring.

Broad, flat sternum with large ventral **carina** (keel) ⇒ large surface to anchor flight muscles.

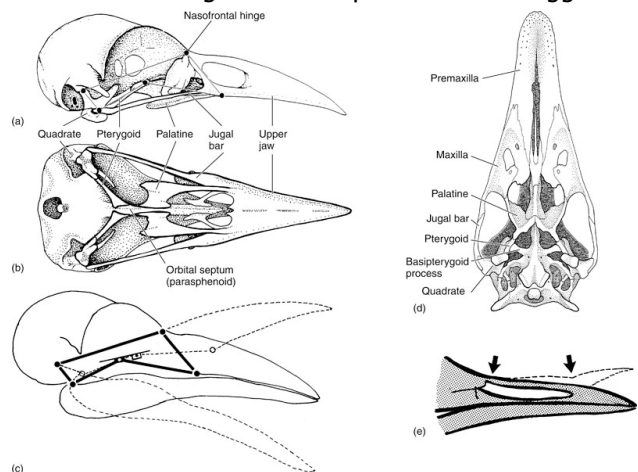
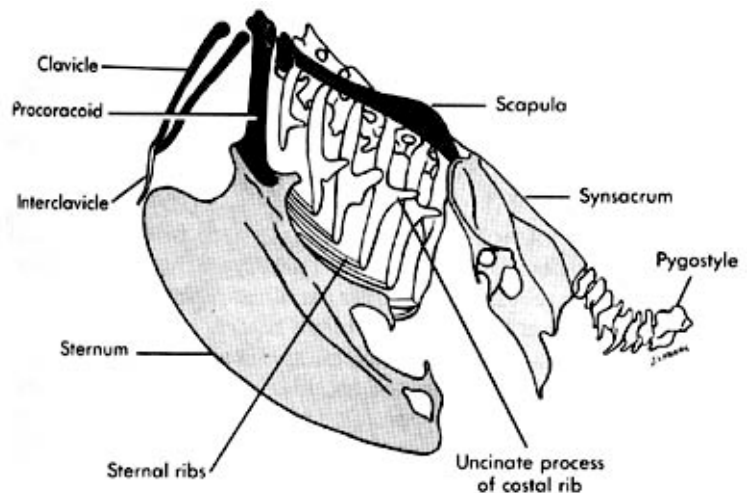
Powerful flight muscles (35% of body mass) — pectoralis (depressor) & supracoracoideus (elevator).

Hand bones modified to form **carpometacarpus** without digits ⇒ bear feathers to extend wing breadth and length without skeletal mass.

Reduced tailbones and fused terminal caudal vertebrae to form the **pygostyle** ⇒ bear tail feathers to extend tail breadth and length without skeletal mass.

Tarsals fuse with other hindlimb bones to form leg bones tibiotarsus & tarsometatarsus. Femur, tibiotarsus & tarsometatarsus all of equal length ⇒ bird can crouch straight down to perch or sit on eggs without displacing center of gravity.

Keratinized bill on jaws ⇒ efficient, lightweight mouthparts without bony, toothy jaws displacing center of gravity. Many birds have flexible symphysis between jugal and nasal bones allowing wider gape and flexing rostrum around items in the mouth to enhance their grip. Some also have a symphysis between the nasal and premaxillae allowing the end of the snout to elevate without opening the mandible — this is especially useful to birds with long bills picking food out of small spaces.



Identify the above structures in the skeleton of the chicken, pigeon, duck, and owl. Compare them with the homologous features of the mammalian skeleton.

Compare the wing bones of the bird with the wing bones of a bat. How must the bat achieve a broad wing surface without feathers? What are the relative advantages of each wing type?

Examine the skeletons, skulls, or skins of the other bird specimens representing eight of the thirty orders of Aves. Focus specifically on differences in feet and bills — apply the concepts we've discussed for mammals to identify specific adaptations relevant to the life history of that order. See **Campbell, Figure 34.31**.

- ❖ order: **Passeriformes** (songbirds, sparrows, crows, jays [$>50\%$ of bird spp.])
- ❖ order: **Columbiformes** (pigeons, doves)
- ❖ order: **Galliformes** (chickens, turkeys, pheasants)
- ❖ order: **Anseriformes** (ducks, geese)
- ❖ order: **Falconiformes** (hawks, eagles)
- ❖ order: **Strigiformes** (owls)
- ❖ order: **Pelecaniformes** (pelicans, cormorants, boobies)
- ❖ order: **Ciconiiformes** (herons, storks)

Key Terms & Concepts

➤ **Ossification: intramembranous / endochondral**

➤ **Bone tissue: compact / spongy**

- ❑ lacuna / osteocytes / central canal

➤ **Bone: process / foramen / joint**

- ❑ suture / symphysis / diarthrosis
- ❑ condyle / fossa / ligament
- ❑ hinge / ball-and-socket / pivot

➤ **Skeleton, axial:**

- ❑ visceral skeleton
- ❑ skull:

- cranium: occipital condyle / nuchal crest / sagittal crest / mandibular fossa
- facial bones: zygomatic arch / rostrum / hard palate
- mandible: dentary / mandibular condyle / angular, condyloid, & coronoid processes
- heterodont: incisors / canines / cheek teeth — premolars & molars
- ❑ vertebral column: cervical / trunk — thoracic & lumbar / sacrum / caudal
 - vertebrae: notochord / centrum / intervertebral disk / neural arch / spinal cord / neural spine / transverse process / anterior facet / posterior facet

➤ **Skeleton, appendicular:**

- ❑ pectoral girdle: clavicle / scapula
- ❑ pelvic girdle: pubic symphysis
- ❑ forelimb: humerus / radius & ulna / carpals / metacarpals / phalanges
- ❑ hindlimb: femur / tibia & fibula / tarsals / metatarsals / phalanges

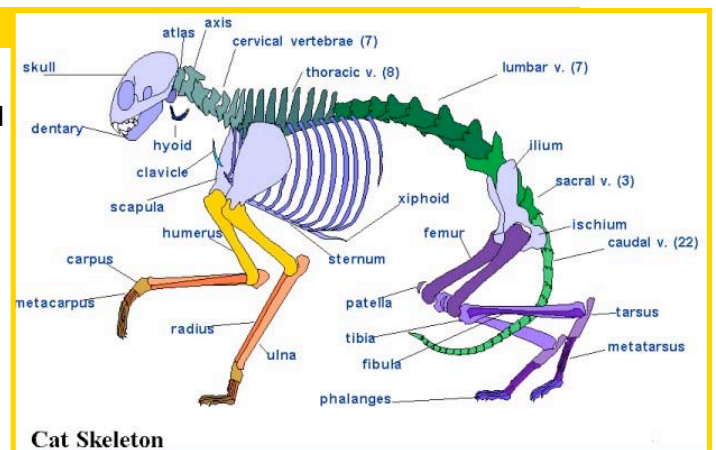
➤ **Locomotion: aquatic / arboreal / cursorial / fossorial / saltatorial / volant**

➤ **Stride = stride length x stride rate**

- ❑ stride rate vs. stride force: $L_i/F_i/V_i$ vs. $L_o/F_o/V_o$
- ❑ plantigrade / digitigrade / unguligrade

➤ **Flight Specialization**

- ❑ **synsacrum unciniate process / furcula / carina / carpometacarpus / pygostyle**



- **Keratin: bill / claw / hoof / feather**
- **Adaptation: limbs & jaw**

Useful links for this lab:

Zoology lab at University of Wisconsin-La Crosse:

http://www.bioweb.uwlax.edu/zoolab/Table_of_Contents/Lab-9b/Cat_Skeleton_1/cat_skeleton_1.htm

http://www.bioweb.uwlax.edu/zoolab/Table_of_Contents/Lab-9b/Bird_Skeleton_1/bird_skeleton_1.htm

Will's skull site:

<http://www.skullsite.co.uk/lists.htm>

Digital Morphology:

<http://www.digimorph.org/index.phtml>