CHAPTER 48: VERTEBRATES

CHAPTER SYNOPSIS

The phylum Chordata includes the animals with which we are most familiar and most closely related. Their principal features are: a single, hollow, dorsal nerve cord; a flexible, dorsal notochord; pharyngeal slits; and a postanal tail. The most primitive chordates include tunicates and lancelets. Larval tunicates resemble primitive tadpoles and clearly possess all chordate characteristics. Adult tunicates are sessile, colonial organisms that secrete a cellulose tunic around themselves. They seemingly lack many of the expected characteristics. The lancelets are scaleless, fishlike marine organisms. They are filter feeders and create water currents via cilia on the anterior end of the gut.

The subphylum Vertebrata is well-represented by marine, freshwater, and terrestrial organisms. They possess a vertebral column, a dorsal nerve cord protected by the vertebrae and have a distinct skull that encloses the brain. Their circulatory and excretory systems are markedly different from all other animals. Vertebrates are divided into eight classes; four contain the aquatic fishes and four are terrestrial tetrapods.

The class Myxini include the lampreys, and the class Cephalaspidomorphi includes the hagfish. Both are commonly labeled jawless fish and are often lumped into the superclass Agnatha. Both retain the notochord as adults and possess cartilaginous skeletons. Larval lampreys superficially resemble the lancelets, although they are more efficient feeders and create water currents via a muscular pharynx. The cartilaginous Chondrichthyes and the bony Osteichthyes are jawed fishes. The horizontal fins of the sharks and rays improve their swimming ability, forcing the buoyant animals downward in the water as they swim forward. Their skin is covered by small denticles from which teeth are derived. Bony fish possess a denser, less buoyant skeleton and have evolved a gas-filled swim bladder to help position themselves in the water. Their scales are composed of thin, bony plates and they possess a well-developed lateral line sensory system. Bony fish are divided into two groups, the lobe-finned fish like the coelocanth and lungfish, and the ray-finned fish, most other fish. Bony fish possess several unique characteristics including gills, a gill cover, and a single-loop circulation.

Terrestrial vertebrates include the classes Amphibia (frogs and salamanders), Reptilia (lizards and snakes), Aves (birds), and Mammalia (mammals). They evolved from the lobe-finned fishes. As the first land-dwelling vertebrates, amphibians needed to invent certain characteristics to ensure their survival. Among these are: legs and strong thoracic skeletons for support and locomotion, efficient air-breathing structures (lungs) as gills collapse out of water, a redesigned heart and circulatory system to deliver more oxygen to the walking muscles, water-bound reproduction to keep their eggs from desiccation and a means to keep their own bodies from drying out. The three orders of amphibians are Anura (frogs and toads), Urodela (salamanders and newts), and Apoda (caecilians). All are greatly dependent on maintaining a moist skin for respiration except for the dry-skinned toads.

Reptiles are less dependent upon water having more complex lungs, scaly water-tight skins, and leathery amniotic eggs. Their legs are better positioned for mobility and speed, and their heart and circulatory systems are more efficient. Four major forms of reptiles took turns dominating the land. In order they are the pelycosaurs, the therapsids, the thecodonts, and the dinosaurs. Today's reptile orders include Chelonia (turtles and tortoises), Rhynchocephalia (tuataras), Squamata (snakes and lizards), and Crocodilia (alligators and crocodiles). Fishes, amphibians, and reptiles are ectothermic animals; they regulate their body temperature by taking in heat from the environment. Birds and mammals are endothermic; they maintain their temperature by the expenditure of internal energy.

Birds are clearly evolved from reptilian ancestors. Their feathers are modified reptile scales. Feathers are obviously important for flight, but also insulate as birds are endotherms.

They need to maintain a high body temperature so that metabolism in their flight muscles can proceed at a faster rate. Birds lay hard-shelled eggs and have extremely efficient respiratory and circulatory systems to provide sufficient oxygen to sustain flight. Bird bones are thin and hollow to reduce weight. Many are fused to provide rigidity for flight. Birds are the only vertebrates that have a fused collarbone (wishbone) and a keeled breastbone.

Mammals evolved from therapsids reptiles over 220 million years ago. They were a minor group as long as the dinosaurs flourished. With their extinction, mammals rapidly diversified. The key characteristics of mammals are milk-producing glands and hair. Mammal hairs are not derived from reptile scales or bird feathers, though they serve a similar protective, insulating function. Monotremes are egg-laying mammals that retain many primitive, reptilian characteristics. Marsupials are the pouched mammals found almost exclusively in Australia. Placental mammals produce a true placenta that nourish their embryos through the course of development. Both marsupials and placental mammals give birth to live young and nourish them with milk. Other characteristics of mammals include teeth, specialized digestive systems for eating plants, horns and hooves, and special adaptations associated with flight. Although not the most numerous vertebrates, because of their size, mammals are certainly among the most obvious.

CHAPTER OBJECTIVES

- Indicate the four principal characteristics of chordates.
- Compare the two non-vertebrate chordates with each other and to the vertebrates.
- Indicate the major characteristics possessed by all vertebrates and those features that separate them into eight classes.
- Understand how the agnathans differ from all other vertebrates.
- Explain the value of the Chondrichthyes skeleton and indicate the structure(s) the Osteichthyes evolved to counteract the comparative disadvantage of their skeleton.
- Know the characteristics required to evolve a terrestrial form of life from an aquatic one.
- Understand how amphibians differ from the three other classes of terrestrial vertebrates.
- Describe how the reptiles are evolutionarily more advanced than amphibians and why they are better adapted for a truly terrestrial existence.
- Differentiate between endothermy and ectothermy, the advantages and disadvantages of each, and indicate which classes of vertebrates fit into each category.
- Understand the special adaptations found in the class Aves.
- Differentiate among monotremes, marsupials, and placental mammals.

KEY TERMS

allantois
amnion
anapsid
chordate
chorion
craniate chordate
diapsid
ectothermic
endothermic
homeothermic
metamorphosis
nerve cord
notochord
pharyngeal slits
pharynx
poikilothermic
postanal tail
synapsid
tetrapod
tunic
yolk sac

CHAPTER OUTLINE

48.0 Introduction

I. CHORDATES IMPROVED THE ENDOSKELETON

A. Truly Internal Bony Skeleton fig 48.1

B. Muscles Attach to a Flexible Skeleton
1. Allows for greater range of movement
2. Allows for development of vertebrates which include large animals

48.1 Attaching muscles to an internal framework greatly improves movement

I. THE CHORDATES

A. Characteristic Features of the Phylum Chordata
1. Are deuterostome coelomates
2. Characterized by notochord, jointed appendages, segmentation
3. Include birds, reptiles, amphibians, fishes, mammals

B. Chordates Exhibit Four Principal Features fig 48.2
1. Single, hollow dorsal nerve cord
   a. Runs just below dorsal surface
   b. Differentiates into brain and spinal cord in vertebrates
2. Flexible, dorsal notochord
   a. Forms on dorsal side of primitive gut in embryo
   b. Located just below nerve cord
   c. Persists in same form in some nonvertebrate chordates
   d. Replaced by vertebral column in vertebrate embryological development
3. Pharyngeal slits
   a. Pharynx connects mouth cavity and esophagus to outside
   b. Slits in most vertebrates don't connect to outside, form pharyngeal pouches
   c. Present in vertebrate embryos, lost in adult terrestrial forms
   d. Structures in embryos are clue to aquatic ancestry of group
4. A postanal tail
   a. Extends beyond the anus
   b. Present in embryo if not in adult form
   c. Other animals have terminal anus
5. All four features present at some time in life of chordates
   a. Human embryos have pharyngeal slits, dorsal nerve cord, notochord
   b. Adult humans have nerve cord
   c. Also have pair of pharyngeal slits that become Eustachian tubes to middle ear
6. Additional general features
   a. Segmented body plan, most visible in blocks of embryonic muscle fig 48.3
   b. Internal skeleton against which muscles work for locomotion fig 48.4

48.2 Nonvertebrate chordates have a notochord but no backbone

I. THE NONVERTEBRATE CHORDATES

A. Tunicates fig 48.5a,b
1. Subphylum Urochordata
2. Most specimens are sessile as adults, may be colonial
   a. Possess notochord and nerve cord only in larval stage
   b. Adults lack body cavity and visible segmentation
3. Adults are filter feeders
   a. Create water currents with ciliary action
   b. Stream of water drawn into pharynx
   c. Food particles trapped in mucus produced by endostyle
4. Tadpole-like larvae appear distinctly different from adults fig 48.5c
   a. Exhibit all chordate characteristics
   b. Do not feed and have a poorly developed gut
   c. Free-swimming until they attach to substrate with sucker
5. Adults change vastly in appearance
   a. Difficult to discern evolution by examining adult form
   b. Adults secrete a cellulose tunic around themselves
   c. Colony of individuals may possess common sac and external opening
   d. Many possess symbiotic photosynthetic bacteria
6. Origin of vertebrates may have involved larval tunicate with ability to reproduce

B. Lancelets
1. Subphylum Cephalochordata
2. Scaleless, fishlike marine organisms
   a. Notochord runs entire length of body and persists in adults
   b. Bury selves in mud or sand, expose anterior end only fig 48.6
   c. Segmentation of muscles readily visible as discrete blocks
   d. Have more pharyngeal gill slits than fishes
3. Skin only one cell layer thick, lacks pigmentation
4. No obvious head or sensory structures other than pigmented light receptors
5. Filter feeders
   a. Create water currents via cilia on anterior end of gut fig 48.7
   b. Possess an oral hood with tentacles that extend beyond the mouth
6. Sexes separate, hard to differentiate externally
7. True primitive condition, unlikely that they evolved from degenerate fishes

48.3 The vertebrates have an interior framework of bone

I. CHARACTERISTICS OF VERTEBRATES

A. Vertebrates Possess a Spinal Column
1. Name of subphylum derived from bony vertebral segments in spine
2. Differ from tunicates and lancelets in two ways
   a. Possess a vertebral column
      1) Notochord replaced by bony vertebral column
      2) Hollow tube of bones protecting dorsal nerve cord fig 48.8
   b. Possess a head
      1) Exhibits distinct head, with skull and brain
      2) Group also called craniate chordates

B. Other Important Differences Between Vertebrates and Other Chordates
   1. Neural crest
      a. Unique group of embryonic cells develop on crest of neural tube
      b. Associated with neural plate pinching together to form neural tube
      c. Neural crest cells migrate through body forming various structures
   2. Internal organs
      a. Possess characteristic liver, kidneys, endocrine glands
      b. Have a heart and closed circulatory system
      c. Circulatory, excretory functions much different from other animals
   3. Endoskeleton
      a. Composed of bone or cartilage
      b. Special tissue containing collagen protein coated with calcium phosphate salt
         1) Collagen fibers laid down first, provide flexibility
         2) Calcium minerals infiltrate fibers, provide rigidity
      c. Bone is strong without being brittle like chitin is
      d. Provides for great size and movement of this group

C. Overview of the Evolution of Vertebrates
   1. First vertebrates were marine, without jaws or paired fins
   2. Jawed fishes then became dominant creatures in the sea
   3. Amphibian ancestors first to invade the land
   4. Replaced by reptile more suited to live out of water
      a. Dinosaurs ruled the earth for 150 million years
      b. Mammals became dominant 65 million years ago
      c. Dinosaurs and mammals coexisted 220 million years ago
   5. Extinction of dinosaurs favored domination of land by mammals
   6. Eight principal classes of vertebrates fig 48.9
      a. Four classes are aquatic fishes
         1) Class Myxini: Hagfish (Superclass Agnatha)
         2) Class Cephalaspidomorphi: Lampreys (Superclass Agnatha)
         3) Class Chondrichthyes: Cartilaginous sharks, skates, and rays
         4) Class Osteichthyes: Bony fishes
      b. Four classes are terrestrial tetrapods
         1) Class Amphibia: Salamanders, frogs, and toads
         2) Class Reptilia: Reptiles
         3) Class Aves: Birds
         4) Class Mammalia: Mammals

48.4 The evolution of vertebrates involves successful invasions of sea, land, and air

I. FISHES

A. A Diverse and Successful Group fig 48.10
   1. Provided evolutionary basis for invasion of land by amphibians
      a. Amphibians viewed as transitional form, a fish out of water
      b. Share common features, with differences as well
   2. Major classes of fish tbl 48.1
   3. The first fishes appeared over 505 million years ago fig 48.11
      a. Jawless, toothless filter feeders, breathed with gills, had tail but no fins
      b. Only existing vertebrates for 50 million years
         1) Developed fins by end of period
         2) Had massive bone shields protecting the head and neck
         3) Jawed fishes appeared later, as did cartilagenous and bony fishes

B. Characteristics of Fishes
   1. Vary in size, shape, color, and appearance
   2. Live in a variety of habitats
   3. Common characteristics
      a. Gills
         1) Extract dissolved oxygen from water around them
         2) Swallowed water passes over filaments rich in blood vessels
         3) Located at back of pharynx, supported by arches of cartilage
         4) Blood moves opposite the flow of water to maximize oxygen absorption
      b. Vertebral column
         1) Internal skeleton with spine surrounding dorsal nerve cord
         2) Skeleton may or may not be made of bone
         3) Brain fully encased in protective skull of bone or cartilage
      c. Single-loop blood circulation
         1) Blood pumped from heart to gills
         2) Oxygenated blood from gills passes to rest of body
         3) Heart is series of four chambers that contract in sequence
      d. Nutritional deficiencies
         1) Unable to synthesize aromatic amino acids
         2) All vertebrates must consume these amino acids in their diet

II. HISTORY OF THE FISHES

A. The First Fishes
   1. Comprised five Ostracoderm orders
      a. Head-shields made of bone
      b. Internal skeleton was made of cartilage
      c. Thrived in Ordovician and Silurian periods, almost extinct by Devonian
      d. Survived by the Agnatha: Parasitic lampreys and hagfish fig 48.12
   2. Invention of jaws occurred 410 million years ago fig 48.13
      a. Evolved from modified gill arch-supports, the area between gill slits
         1) Gill arch formed by cartilage looking like a sideways V
         2) Modifications of arches resulted in modern jaws
         3) Teeth evolved from modified scales on skin that lined the mouth
      b. Accomplished by members of order Acanthodia, spiny sharks
         1) Internal skeletons of cartilage
         2) Skin scales contained small plates of bone
         3) Were predators, more efficient swimmers that ostracoderms
         4) Possess maximum of 7 paired fins, reinforced with spines
         5) All spiny sharks are extinct
      c. Evolution of heavily armored placoderms
         1) Dominant during Devonian, extinct by its end
         2) Front of body heavily armored, rear was completely naked
         3) Jaw improved with upper jaw fused to skull

B. The Rise of Active Swimmers
   1. Pioneer vertebrates replaced by sharks and bony fishes
   2. Further improvement of the jaw
      a. First gill arch behind jaw became supporting strut
      b. Joined rear of lower jaw to rear of skull
      c. Allowed mouth to open very wide, an efficient weapon
   3. Superior, streamlined design for swimming

4. Mobile fins increased swimming ability
   a. Caudal fin provides propulsion, moves side-to-side
   b. Dorsal and ventral fins are stabilizers
   c. Paired pectoral and pelvic fins, give directional movement and brakes

C. Sharks Become Top Predators
1. Occurred more than 280 million years ago, in the Carboniferous Period
   a. Class Chondrichthyes
   b. Shark skeleton is made of cartilage that is calcified in outer layers
   c. Large pectoral fins improved swimming enormously fig 48.14
   d. Aggressive predators that achieved large size
2. Among first vertebrates to develop teeth
   a. Teeth sit on top of jaw, not firmly anchored in it
   b. Teeth lost readily, replaced by one from row behind
   c. Skin covered with tooth-like scales with a sandpaper texture
3. Reproduction in sharks is advanced for a fish
   a. Internal fertilization
   b. Eggs generally develop in female's body, young born alive
4. Extinction of many varieties at end of Permian Period (248+ million years ago)
   a. Followed by burst of evolution during age of dinosaurs
   b. Flattened skates and rays evolved at this time

D. Bony Fishes Dominate the Water
1. Class Osteichthyes, bony fish, evolved at same time as sharks fig 48.15
   a. Developed heavy skeleton made completely of bone
      1) Process of ossification replaces cartilage with bone
      2) External plates and scales also ossified
      3) May have evolved from spiny sharks
   b. Extremely successful group
2. Unlike sharks, bony fishes evolved in fresh water
   a. Had air sacs at back of throat for buoyancy
   b. Have highly mobile fins, thin scales, and symmetrical tails
3. Became divided into two groups
   a. Lobe-finned fish: Ancestors of land mammals
   b. Ray-finned fish: Ancestors of most modern fish
      1) Internal skeleton of bony rays supports and stiffens each fin
      2) No muscles within fins
      3) Air sacs transformed into an air pouch for buoyancy

E. Important Adaptations of Bony Fishes
1. Swim bladder
   a. Gas-filled sac that allows regulation of buoyant density
   b. Fish can remain suspended at any depth in the water fig 48.16
   c. Sharks must move through the water or sink
   d. Fills with gases, oxygen and nitrogen, then drained of them
      1) Gas released from blood
      2) Exchange occurs across wall of swim bladder and nearby blood vessels
      3) Controlled by a variety of physiological factors
2. Lateral line system
   a. Series of sensory organs that project into a canal beneath skin surface
   b. Organs deflected by movement of water as it passes over them
   c. Fish can assess rate of movement through water
   d. Fish can also detect motionless objects by water deflection off them
   e. Terrestrial vertebrate sound receptors very similar to these organs

3. Gill cover
    a. Hard plate covering gills called the operculum
    b. Flexion of covers pumps water over gills
    c. Volume of cavity increased when mouth open and gill cover closed
    d. Closing mouth and opening operculum decreases volume of mouth cavity
    e. Forces water over gills to outside
    f. Water moves over gills while fish is stationary

F. The Path to Land
1. Lobe-finned fishes comprise seven modern species fig 48.17
    a. Include coelocanth and six species of lung fish
    b. Paired fins consist of fleshy, muscular lobe supported by bone core
    c. Bony rays only at tip of fin
    d. Muscles move fin rays independently of one another
2. Amphibians most certainly evolved from this group

III. AMPHIBIANS

A. Characteristics of Living Amphibians
1. Class Amphibia classified into three orders tbl 48.2
    a. Order Anura: Frogs and toads
    b. Order Urodela (Caudata): Salamanders and newts
    c. Order Apoda (Gymnophiona): Caecilians

B. Key Characteristics
1. Legs
    a. Frog and salamanders have 4 legs
    b. Absent in caecilians, lost in adapting to burrowing
2. Cutaneous respiration
    a. Frogs, salamanders, and caecilians supplement lung respiration
    b. Moist skin provides extensive surface area
    c. Efficient only for high surface-to-volume ratio
3. Lungs
    a. Internal surfaces are not as well developed as in reptiles or mammals
    b. Breathe by moving floor of mouth to suck air in
4. Pulmonary veins
    a. Veins return blood from lungs to heart
    b. Aerated blood leaves heart at greater pressure than lungs
5. Partially divided heart
    a. First chamber of heart in fish is missing in amphibians
    b. Second and last chambers separated by wall
    c. Prevents aerated blood from lungs from mixing with nonaerated blood from body
    d. Provides separate pulmonary and systemic pathways
    e. Separation is imperfect since third chamber is not divided
6. Additional characteristics
    a. Zone of weakness between base and crown of teeth
    b. Possess sensory rod in retina called a “green rod”

IV. HISTORY OF THE AMPHIBIANS

A. Are Animals of Two Worlds
1. Able to live in water and on land
2. Aquatic world is reminiscent of fish ancestors
3. Terrestrial world is the land they first invaded

B. Origin of Amphibians
   1. Likely evolved from lobe-finned fishes, which group is arguable
      a. Internal anatomy resembles coelocanth
      b. Lungfish and rhipidistians have openings in mouth similar to nostrils
      c. Lungfish have paired lungs
      d. DNA analysis shows closer relationship to lungfish than coelocanths
      e. Pattern of skull and bones show greater resemblance to rhipidistian fishes
   2. Innovations associated with invasion of land
      a. Legs to support body weight and for movement — fig 48.18
      b. Lungs needed because gills require buoyancy of water for support
      c. Redesigned heart to deliver more oxygen to walking muscles
      d. Water-bound reproduction to prevent eggs from drying out
      e. Needed to devise means to keep body from drying out

C. The First Amphibian
   1. Earliest amphibian fossil, *Ichthyostega*, found in Greenland — fig 48.19
   2. For 100 million years, amphibian fossils found only in North America
   3. Spread throughout world when Pangaea formed
   4. Strongly built animal with four well-supported legs
      a. Backbone more substantial than in fish
      b. Long, broad overlapping, inflexible ribs encased lungs and heart
      c. Likely breathed by raising and lowering floor of mouth

D. Rise and Fall of Amphibians
   1. Common during Carboniferous Period (360-280 million years ago)
   2. Shared wet tropical environment with early reptiles
   3. Moved into dry upland regions during Permian Period (286-249 million years ago)
      a. Developed bony plates and armor, some grew to pony size — fig 48.20
      b. Developed leathery skin to prevent water loss
      c. Didn't breathe through skin like most modern amphibians
   4. Ousted from niche by therapsid reptiles by end of Permian
      a. Only 15 families of amphibians by end of Triassic
      b. Only two groups, anurans and urodeles, through the Jurassic

E. Amphibians Today
   1. Current amphibians all descended from 2 groups
      a. Expansion during Tertiary Period (65-63 million years ago) into wet habitats
      b. Presently 37 families and over 4,200 species
   2. Anura
      a. Include frogs and toads, amphibians without tails — fig 48.21a
         1) Frogs have smooth, moist skin; long legs; live in or near water
         2) Toads have bumpy, dry skin; short legs; are adapted to dry environments
      b. Are carnivores, eat a wide variety of insects
      c. Return to water to reproduce
         1) Eggs lack water-tight membranes and dry out readily
         2) Eggs fertilized externally
         3) Eggs hatch into algae-eating, swimming larval tadpoles
         4) Larva metamorphose into adult forms after a period of growth
   3. Urodela (Caudata)
      a. Have elongated bodies, long tails, and smooth moist skin — fig 48.21b
      b. Most live in moist places, some live entirely in water
      c. Reproduction
         1) Lay eggs in water or moist areas
         2) Fertilization is external in most species

3) Just-hatched young look like adults, do not undergo profound metamorphosis

4. Apoda (Gymnophiona)
   a. Highly specialized group of burrowing amphibians fig 48.21c
   b. Lack legs, have small eyes, are often blind
   c. Eat worms and soil invertebrates
   d. Male deposits sperm directly into female, young are born alive

V. REPTILES

A. Class Reptilia Improved on Amphibian Innovations to Colonize the Land

1. Legs support body better, enable reptiles to run
2. Lungs and heart are more efficient
3. Skin covered with scales to minimize water loss
4. Eggs encased in water-tight covers fig 48.22
5. First truly terrestrial vertebrates, numerous and highly successful tbl 48.3

B. Key Characteristics of Reptiles

1. Amniotic egg
   a. Water-tight eggs contain food source (yolk) and four membranes fig 48.22
   b. Membranes are: Yolk sac, amnion, allantois, and chorion
   c. Each plays role in making egg an independent life-support system
      1) Just beneath the shell, the chorion allows oxygen to enter, but retains water
      2) Inner amnion encased developing embryo within fluid-filled cavity
      3) Yolk sac sends food from yolk to embryo through amnion via blood vessels
      4) Allantois surrounds cavity into which waste products are excreted
2. Dry skin
   a. Layer of scales or amour cover bodies to prevent water loss
   b. Scales develop as surface cells fill with keratin
   c. Same protein forms human fingernails, hair, and bird feathers
3. Thoracic breathing
   a. Expand and contract rib cage to suck air in and force it out
   b. Capacity limited only be volume of lungs, not the volume of the mouth

VI. THE RISE AND FALL OF DOMINANT REPTILE GROUPS

A. Dominant Large Land Vertebrates

1. Dominance lasted for 250 million years
2. Four forms were dominant in sequence: Pelycosaurs, therapsids, thecodonts, dinosaurs

B. Pelycosaurs: Becoming a Better Predator

1. Early reptiles that evolved water tight eggs
2. Were synapsids
   a. Skulls had paired temporal holes in addition to holes for eyes
   b. Presence and number of holes important to reptile classification fig 48.27
   c. Powerful jaws anchored to holes in the skull
   d. Could bite more powerfully, kill animals their own size fig 48.23
3. Died out 250 million years ago
4. Replaced by direct descendants, the therapsids

C. Therapsids: Speeding Up Metabolism fig 48.24

1. Ate more frequently than ancestors to produce body heat
2. Far more active than other vertebrates of that time, may have been endotherms
   a. Extra food needed to produce body heat
   b. Permitted more activity during long, cold winters

3. Called "mammal-like reptiles," reigned for 20 million years
4. Replaced by cold-blooded thecodont line 230 million years ago
5. Gave rise to descendants, mammals, before extinction 170 million years ago

D. Thecodonts: Wasting Less Energy
1. Diapsid reptiles, had two pairs of temporal holes in skull
2. Were ectotherms like amphibians and early reptiles fig 48.25
3. Endothermy no longer advantageous with warmer climate, needed less food
4. First bipedal land vertebrates, walked on two feet
5. Dominant for 15 million years
6. Replaced by direct descendants, dinosaurs

E. Dinosaurs: Learning to Run Upright
1. Legs positioned directly underneath body fig 48.26
2. Enabled running with speed and agility
3. Hole in side of hip socket distinguishes them from thecodonts
4. Dominated for 150 million years, abruptly went extinct 65 million years ago
5. Evolutionary relationships of amniotes: Reptiles, birds, and mammals figs 48.27, 28

F. Today's Reptiles
1. Of 16 orders of reptiles, only four survive today
2. Turtles
   a. Are most ancient reptile line
   b. Have solid skulls like first reptiles
   c. Have changed little since before time of dinosaurs
3. Lizards and snakes
   a. Most reptiles belong to second line to evolve
   b. Evolved 250 million years ago in late Permian before thecodonts fig 48.28
   c. Became diverse only with disappearance of dinosaurs
4. Tuataras
   a. Rhynchocephalonts are the third linage
   b. Small, diapsid reptiles, appeared shortly before dinosaurs
   c. Common in Jurassic, declined in Cretaceous
   d. Unable to compete with lizards, two species survive on islands near New Zealand
5. Crocodiles
   a. Are fourth linage, appeared much later
   b. Descended from same line that produced dinosaurs
   c. Little change in the last 200 million years
   d. Comprise archosaurs along with thecodonts and dinosaurs

G. Other Important Characteristics
1. Internal fertilization
   a. External fertilization not possible since sperm cannot penetrate egg membranes
   b. Male places sperm inside female, fertilize egg before membranes form
2. Circulatory system provides more oxygen to body fig 48.29
   a. Septum in heart extended from atrium partway into ventricle
   b. Tends to decrease mixing of oxygen-poor and oxygen-rich blood in ventricle
   c. Septum totally divides ventricle in crocodiles and birds (and likely dinosaurs)
3. Endothermy versus ectothermy
   a. All living reptiles are ectothermic, obtain heat from external sources
      1) Endotherms generate own heat internally
      2) Homeotherms maintain constant body temperature
      3) Poikilotherms' body temperature fluctuates with ambient temperature

b. Examples
   1) Deep sea fish is ectothermic homeotherm: Heat external, temperature constant
   2) Reptiles are generally ectothermic poikilotherms
   3) Reptiles regulate body temperature by behavior, bask in sun, hide in shade
   4) Crocodiles are ectothermic
   5) Later dinosaurs and descendent birds were endothermic

H. Kinds of Living Reptiles
1. Classified into 4 surviving orders
2. Reptiles occur worldwide, except in coldest regions
3. Order Chelonia: Turtles and tortoises fig 48.30
   a. Turtles generally live in water, tortoises live on land
   b. Only reptiles whose bodies are encased in a protective shell
   c. Lack teeth, but have sharp beak
   d. Are anapsid, lack temporal holes in skull
   e. Composition of shell
      1) Made of hard plates in some, tough leathery skin in others
      2) Composed of two basic parts
         a) Carapace covers dorsal surface
         b) Plastron covers ventral portion
      3) Vertebrae and ribs of most species are fused to inside of carapace
      4) Support for muscle attachment comes from shell
      5) Tortoise shells are dome-shaped, turtle shells are streamlined, disk-shaped
      6) Freshwater turtles have webbed toes, marine turtles have flippers
      7) Marine turtles migrate long distances to lay eggs on land
4. Order Rhynchocephalia: Tuatara
   a. Two species make up entire order, found only on islands off New Zealand
   b. Has conspicuous spiny crest running down back
   c. Has inconspicuous parietal or third eye on top of head
      1) Concealed under scales, has lens, retina, and is connected to brain
      2) May function as a thermostat, protect it from overheating
5. Order Squamata: Lizards and snakes fig 48.31
   a. Suborders Sauria (lizards), Amphisbaenia (worm lizards), and Serpentes (snakes)
   b. Have paired male reproductive organs
   c. Lower jaw not joined directly to skull
      1) Movable hinge with five joints allows flexibility in jaw movements
      2) Lizards lack lower arch of bone below lower opening of skull
   d. Most are predatory carnivores
   e. Lizards versus snakes
      1) Lizards have limbs, snakes do not
      2) Snakes lack movable eyelids and external ears
      3) Lizards are more ancient group
   f. Rely on agility and speed to catch prey and avoid predators
   g. Many lizards can lose tail to escape predator and regenerate new one
6. Order Crocodilia: Crocodiles and alligators fig 48.32
   a. Primitive-looking reptiles, also includes caimans and gavials
   b. Practically unchanged since they evolved from thecodonts 200 million years ago
   c. Live in or near water in tropical or subtropical regions
   d. Are aggressive carnivores, bodies adapted for hunting by stealth
      1) Eyes and nostrils on top of head, lie submerged in water
      2) Enormous mouths with sharp teeth and strong neck
      3) Can feed underwater, valve prevents water from entering air passage
   e. Are more like birds than other reptiles
      1) Both groups care for their young, have four-chambered heart

2) Share other anatomical features
f. Most likely that birds are direct descendants of dinosaurs
g. Crocodiles and birds more closely related to dinosaurs and each other than they are related to lizards and snakes

VII. BIRDS

A. Class Aves Is One of Four Groups to Conquer the Air

1. Flying animals include insects, pterosaurs, birds, bats
2. Success derived from development of the feather
   a. Developed from reptilian scale
   b. Lightweight, readily replaced if damaged
3. Most successful of all terrestrial vertebrates tbl 48.4

B. Key Characteristics of Birds

1. Show that birds are clearly related to reptiles
   a. Lack teeth, have vestigial tail unlike reptiles
   b. Like reptiles, lay amniotic eggs, have scales on feet and lower legs
2. Feathers
   a. Modified reptilian scales
   b. Provide lift for flight and conserve heat
   c. Structure combines maximum flexibility with minimum weight fig 48.33
   d. Develop from pits in skin called follicles
      1) Shaft emerges, pairs of vanes develop on opposite sides
      2) Vanes have branches called barbs
      3) Barbs have projections called barbules, equipped with microscopic hooks
      4) Hooks link barbs to one another
      5) Can be replaced, like scales
   e. Some dinosaurs may also have had feathers
3. Flight skeleton
   a. Bird bones are thin and hollow
   b. Many bones are fused to provide rigidity
   c. Only vertebrate to have fused collarbone (wishbone) or keeled breastbone

VIII. HISTORY OF THE BIRDS

A. The First Bird

1. *Archaeopteryx*, fossils from the late Jurassic fig 48.36
2. Clear impression of feathers in the fossil

B. Birds Are Descended from Dinosaurs

1. *Archaeopteryx* shares features with small therapod dinosaurs
   a. Size of crow, skull has teeth
   b. Very few bones are fused to each other
   c. Bones are solid (bird bones are hollow)
   d. Has long reptilian tail and no breastbone to anchor flight muscles
   e. Has forelimbs of dinosaur
2. Originally classified as coelurosaur *Compsognathus*
3. Distinctly avian
   a. Due to presence of feathers on wings and tail
   b. Also has wishbone, lacking in dinosaurs, but present in thecodonts
4. Recent discovery of feathered dinosaurs in China
   a. *Caudipteryx* is intermediate between *Archaeopteryx* and dinosaurs
   b. Large feathers on tail and arms, other features of velociraptors

c. Had short arms, too short to be wings
d. Feathers likely evolved for insulation not flight
e. When longer arms evolved, dinosaurs properly called birds

5. Birds best placed in own class due to feathers, hollow bones, and super-efficient lungs
   a. Are direct descendants of theropod dinosaurs
   b. As closely related to coelurosaurs as other theropods fig 48.35
6. Fossils from Cretaceous have features of modern birds
   a. Toothed birds with hollow bones and breastbone needed for sustained flight
   b. Other specialized, flightless diving birds
7. Fossil record incomplete, feathers rarely fossilize, hollow bones are delicate
8. Relationships of modern birds inferred from DNA studies
   a. Flightless types like ostrich are most ancient
   b. Ducks, geese, other waterfowl evolved next in early Cretaceous
   c. Followed by woodpeckers, parrots, swifts, owls
   d. Songbirds evolved in mid-Cretaceous
   e. Shorebirds, birds of prey, flamingos, penguins evolved in late Cretaceous

C. Birds Today
1. Beak and feet characterize many bird habits and food
2. Currently 28 orders of birds fig 48.36
3. Internal physiological changes needed to cope with high energy demands of flight
   a. Efficient respiration
      1) Need greater contact surface to absorb enormous quantities of oxygen
         a) Inhaled air goes past lungs to air sacs near and in bones of back
         b) Air then goes to lungs and is exhaled
      2) Air passes through lungs in only one direction, at right angles to flow of blood
      3) Extracts oxygen more efficiently
   b. Efficient circulation
      1) Oxygen captured by lungs must be transported to flight muscles quickly
      2) Wall dividing ventricle is complete, two circulations do not mix
      3) Flight muscles get fully oxygenated blood
      4) Most birds have a rapid heart beat
         a) Hummingbird = 600 times per minute, chickadee = 1,000 bpm
         b) Flightless ostrich = 70 beats per minute, same as human
   c. Endothermy
      1) Dinosaurs were likely endothermic
      2) Birds maintain higher body temperatures than most mammals
      3) Feathers provide insulation to conserve heat
      4) Metabolism in flight muscles proceeds at faster rate

IX. MAMMALS

A. Class Mammalia Is the Least Diverse of Five Classes of Vertebrates fig 48.41
1. Almost all large land vertebrates are mammals, tend to dominate communities
   a. Typical mammal is not large
   b. 3,200 of 4,100 species are rodents, bats, shrews, moles tbl 48.5

B. Key Mammalian Characteristics
1. Hair
   a. Even naked whales and dolphins have bristles on snouts
   b. Allowed for regulation of body temperature, invasion of colder climates
   c. New structure, not derived from reptilian scales or feathers
      1) Each hair extends like stiff thread from bulb-like hair follicle
      2) Composed of dead cells filled with fibrous keratin protein

d. Insulates against heat loss
e. Provides camouflage
f. Whiskers function as sensory structures
g. May serve as defensive weapons as in porcupines and hedgehogs

2. Mammary glands
a. All females possess mammary glands that produce milk
b. Milk is rich in fat, sugar, protein with 95% water
c. High calorie food needed to support rapid growth of newborn

X. HISTORY OF THE MAMMALS

A. Origin of Mammals

1. Arose from therapsids in mid-Triassic, 220 million years ago
a. First mammals were small insectivores
b. Large eye sockets indicate they may have been active at night
2. Mammal jaw reduced to massive bone with a single joint
a. Removed potentially weak junctions
b. Two bones moved to middle ear to make three bone chain that improved hearing

B. Early Divergence in Mammals

1. Were a minor group as long as dinosaurs flourished with only five orders
2. Present as two groups, now considered as subclasses
a. Prototheria
1) Direct descendants of therapsids
2) Small, resembled modern shrews
3) Laid eggs, like ancestors
4) Surviving examples include monotremes: Duckbilled platypus and echidna
b. Theria
1) Includes all other mammals
2) Subdivided into marsupials (pouched mammals) and placental mammals

C. The Age of Mammals

1. Extinction of dinosaurs allowed for rapid diversification of mammals into 19 orders
a. Insulating hair may have prompted survival
b. Rapidly diversified in Tertiary Period
c. Occupied niches previously held by dinosaurs tbl 48.6
2. Reached maximum diversity 15 million years ago
a. Loss of diversity due to changing climates, less tropical habitat
b. Number still declining

D. Characteristics of Modern Mammals

1. Endothermy
a. Allows activity at any time of day or night
b. Supports colonization of severe environments, deserts to ice fields
c. Hair provides insulation to support endothermy
d. Higher metabolic rate required as well
1) More efficient circulation provided by four chambered heart
2) More efficient breathing results from diaphragm breathing muscle
2. Placenta fig 48.38
a. Most mammals are placental and give birth to live young
b. Blood stream of mother and fetus in close contact at placenta
1) Food, water, oxygen pass from mother to child
2) Wastes pass from child to mother, carried away

3. Teeth
   a. Reptiles have homodont dentition, all teeth are the same
   b. Mammal dentition is heterodont
      1) Teeth are highly specialized to match food eaten fig 48.39
      2) Help mammals select and eat a wide variety of foods
      3) Compare teeth of carnivore (dog) and herbivore (deer)
      4) Rodents incisors grow throughout entire life
4. Digesting plants
   a. Most mammals are herbivores, cellulose is major source of food
      1) Mammals lack enzymes to release glucose units
      2) Rely on mutualistic partnership with bacteria that degrade cellulose
   b. Some mammals have four-chambered stomachs
      1) First chamber is largest, holds most cellulose-digesting bacteria
      2) Digested further by rest of stomach
   c. Other mammals digest plant material in the large intestine
      1) Have relatively small stomachs
      2) Bacteria live in pouch called the caecum, off the large intestine
   d. Herbivores must eat a lot of material to gain sufficient nutrition
5. Hooves and horns
   a. Keratin is structural material for claws, fingernails, hooves
      1) Hooves are keratin pads on toes of running mammals
      2) Protect toe, cushion from impact
   b. Horns are composed of a core of bone surrounded by keratin sheath
      1) Horns are not shed, bony core is attached to skull
      2) Outer covering is compacted, hair-like layers
   c. Deer antlers are made only of bone
      1) Male deer grow and shed a set of antlers each year
      2) Covered by thin skin layer of velvet while growing
      3) Velvet dies and is scraped off when antlers are fully grown
      4) Antlers used to attract females, combat males in fall and winter
      5) Shed in spring after breeding season
   d. Rhinoceros horn composed of keratinized hair, no bony core
6. Flying mammals
   a. Bats are only mammals capable of powered flight fig 48.40
   b. Wings are modified forelimbs
      1) Wing is leathery membrane of skin stretched over bones of four fingers
      2) Edges attach to side of body and to hind leg
   c. At rest hang upside down from claws on toes
   d. Evolved sonar system to navigate in dark and find insects
      1) High frequency pulses emitted through mouth or nose
      2) Sound waves reflect off objects, captured by ears

E. The Orders of Mammals
1. Modern mammals comprise nineteen orders
   a. Seventeen are placental
   b. Two are non-placental, monotremes and marsupials
2. Monotremes: Egg-laying mammals fig 48.41a
   a. Includes duck-billed platypus and two species of echidna (spiny anteaters)
   b. Retain a few reptilian characteristics
      1) Lay shelled eggs
      2) Structure of shoulder and pelvis similar to early reptiles
      3) Have a cloaca
         a) Single opening like reptiles
         b) Feces, urine, and reproductive products leave the body at same point

4) More closely related to early mammals than any other mammal
c. Possess fur and functioning mammary glands like other mammals

3. Marsupials: Pouched mammals fig 48.41b
   a. Major difference in embryonic development of marsupials and other mammals
      1) Marsupial fertilized egg is surrounded by chorion and amnion
      2) No shell forms around egg as in monotremes
      3) Marsupial embryo nourished by abundant yolk within egg
      4) Short-lived placenta forms from chorion just before birth
      5) In as few as eight days after fertilization an embryonic marsupial is born
      6) Crawls into marsupial pouch, attaches to nipple, continues to develop
   b. Evolved shortly before placental mammals, 100 million years ago
   c. Nearly all of today's species live in Australia and South America
      1) Both areas are historically isolated
      2) Marsupials in Australia and New Guinea have diversified to fill niches otherwise held by placental mammals
      3) Virginia opossum is the only marsupial in North America
4. Placental mammals fig 48.41c
   a. Produce true placenta that nourishes embryos for entire development
      1) Placenta forms early in course of development
      2) Held in womb of mother, contains abundant fetal and maternal blood vessels
      3) Fetal placenta formed from membranes of chorion and allantois
      4) Maternal placenta formed from wall of uterus
   b. Young undergo considerable development before being born
   c. Major orders of placental mammals tbl48.6

INSTRUCTIONAL STRATEGY

PRESENTATION ASSISTANCE:

Discuss: flight and the anatomy of wings in insects, birds, and mammals; the developmental stage at which monotremes, marsupials, and placental mammals are born; the evolution of birds and mammals from reptiles with respect to the development of feathers and fur.

Discuss endothermy versus ectothermy relative to the structure of the cardiovascular system, overall metabolic activity, the amount of food ingested, and body insulation.

VISUAL RESOURCES:

Compare the larval stages of tunicates, lancelets, and lampreys.

Obtain the jaw of a small shark to show the several rows of teeth. Also find a piece of shark skin to tactilely illustrate the denticles.