

Skeletal System

- Importance to the study of comparative anatomy
 - Bone is readily fossilized
 - The skeleton is generally conservative
 - Responds to important environmental and habitat changes
- Connective Tissue
 - “Living cells embedded (surrounded, suspended) in a non-living matrix (ground substance).”
 - Includes: bone, cartilage, tendons, ligaments, blood
 - All arise from a special mesodermal tissue called **mesenchyme**

- Cartilage
 - Living cells (**chondrocytes**) isolated in pockets (**lacunae**) and surrounded by a non-living ground substance (**chondromucoprotein**).
 - Covered by dense regular connective tissue **perichondrium**.
 - Formed by **chondrogenesis** from inner layer of perichondrium.
 - Two basic types:
 1. **hyaline cartilage** – precursor of replacement bone, also found on articular surfaces.
 2. **fibrous cartilages** – includes:
 1. fibrocartilage
 2. elastic cartilage
 3. calcified cartilage

- Bone
 - Living cells (**Osteocytes**) isolated in pockets (**lacunae**) and surrounded by a non-living ground substance (**hydroxyapatite**).
 - Covered by dense regular connective tissue **periosteum**.
 - Osteocytes intercommunicate via tiny **canaliculi**
 - **Haversian Systems** provide bone with a generous supply of blood vessels and nerves.

Skeletal System

- Classification of Bone - by type of ossification
 1. DERMAL BONE (Membrane Bone)
 - Forms in the dermis
 - Undergoes direct ossification, is not preformed in cartilage.
 - Grows by accretion only.
 2. ENDOCHONDRAL BONE (Replacement Bone)
 - Formed by **endochondral ossification**, is performed in hyaline cartilage.
 - Endochondral Ossification
 - Structure formed first as cartilage.
 - **Diaphysis** - **primary center of ossification**
 - **Epiphyses** - **secondary centers of ossification.**
 - Initially are separated from the diaphysis by growth zones (**zone of proliferating cartilage**)

THE VERTEBRATE SKELETON

- Dermal Skeleton - Vertebrate Exoskeleton
 - Forms the bone of dermal scales
 - prominent in ancient fishes, boney fishes
 - restricted in tetrapods, to skull, jaw and pectoral girdle elements
- Endoskeleton - Deep (internal) structures - 3 divisions
 1. Somatic Skeleton
 - Axial Skeleton - notochord, braincase, vertebral column, ribs, and sternum
 - Appendicular Skeleton - paired appendages, pectoral and pelvic girdles

2. Visceral Skeleton -
 - skeletal elements of the gills and structures evolutionarily derived therefrom. e.g. some elements of upper and lower jaws, middle ear bones of higher vertebrates
3. Heterotopic Bones - miscellaneous bones, formed by direct ossification
 - Sesamoid Bones - form along tendons, e.g. patella
 - interventricular bone in heart of certain ungulates (os cordis of deer)
 - eyelid bones - crocodiles
 - epipubic bones of proto and metatherians
 - os penis (baculum), os clitoris (balbella) of mammals - heterotopic bones that support the external genitalia of some mammals

AXIAL SKELETON

- Centra (pleurocentra): Main body of the vertebrae
 - Types vary based on the form of the articulating faces
- 1. amphicelous:
 - Occurs in primitive and some living reptiles as well as most teleost fish.
- 2. procelous:
 - Occurs in most living reptiles.
- 3. opisthocelous:
 - Occurs in turtles
- 4. acelous:
 - Common in many mammals
- 5. heterocelous:
 - Turtle and bird cervical vertebrae

AXIAL SKELETON

- Intercentrum (hypocentrum)
 - Situated ventrally between successive centra
 - Hemal Arches (chevrons, or chevron bones) = tail intercentra
 - **Capitulum** of the ribs primitively articulated to the intercentrum.
 - In most amniotes, attachment of the rib is shifted to the centrum and forms the **parapophysis**

AXIAL SKELETON

- Neural Arch
 - Extends dorsally from the centrum on either side of the spinal cord and fuses into the **neural spine**.
 - Transverse Process (= **Diapophysis**)
 - articulation of the **tuberculum** of the rib on either side of the neural arch
 - Zygapophyses
 - paired articulations between successive neural arches
 - **Prezygapophyses** - face upward and inward
 - **Postzygapophyses** - face downward and outward
 - Intervertebral Foramina
 - openings between successive neural arches through which the spinal nerves pass

EVOLUTION OF THE CENTRUM **and INTERCENTRUM**

- **Paired basiventral arch bases**
 - provide attachment for ventral ribs.
- **Paired basidorsal arch bases**
 - provide attachment for neural arch.
- **Paired interventral and interdorsal**
 - fuse during development to form the intercentra.
- Paired neural arches

EVOLUTION OF THE CENTRUM **and INTERCENTRUM**

- **Rachitinous Vertebrae**
 - Each vertebral element is comprised of:
 - **hypocentrum** (intercentrum)
 - **pleurocentra** (centra)
 - **Neural arch** - contained zygapophyses

VARIATION IN VERTEBRAE - **FUNCTIONAL DIVISIONS**

- **FISHES**
 - Caudal vertebrae distinguished (from trunk vertebrae) by presence of hemal arch/spine.
- **TETRAPODS**
 - Sacral Region
 - modification for accommodation of the pelvic girdle
 - Functionally divides the vertebral column into **Presacral**, **Sacral**, and **Caudal** Regions
 - Amphibians - single sacral vertebra;
 - Reptiles/Birds - 2 or more sacrals;
 - Mammals 3-5 sacrals
 - Presacral Vertebrae - can be divided into:
 - **Cervical** Vertebrae
 - **Trunk** Vertebrae - may be divided into **thoracic** (with ribs) and **lumbar** (without ribs).

LENGTH AND SPECIALIZATION OF VERTEBRAL COLUMN

- **PRIMITIVE AMPHIBIANS**
 - About 30 presacrals, single sacral, 50 or more caudals
- **MODERN AMPHIBIANS**
 - Salamanders - similar to primitive
 - Caecilians - 200 or more relatively undifferentiated vertebrae
 - Anurans - axial skeleton greatly modified through reduction and fusion.
 - 10 total elements: 1 cervical, 7 trunk, 1 sacral, **Urostyle**.
- **MODERN REPTILES**
 - variable, from 100's of relatively undifferentiated vertebrae in snakes, to relatively few vertebrae in turtles.

LENGTH AND SPECIALIZATION OF VERTEBRAL COLUMN

- **BIRDS**
 - cervicals variable in number
 - thoracics fused
 - **Synsacrum** - fused posterior thoracic, lumbar, sacral and anterior caudal vertebrae, ilium and ischium.
 - **Pygostyle** - fusion of the 4 to 7 terminal vertebrae.
- **MAMMALS**
 - cervicals - 7; except for sloths and sea cows
 - thoracics and lumbar - number varies
 - sacral - 3 to 5 in most (but up to 13)
 - caudals - variable in number (3-50 may be fused to form **coccyx**).

ARTICULATION OF THE SKULL AND VERTEBRAL COLUMN

- **FISHES**
 - **occipital condyle** single
- **AMPHIBIANS - MODERN**
 - paired occipital condyles -
- **REPTILE AND BIRDS**
 - occipital condyle remains single
 - develop **atlas-axis** complex
 - Atlas = proatlas + neural arch₁ + intercentrum₁
 - Axis = centrum₁ + intercentrum₂ + centrum₂ + neural arch₂
- **MAMMALS**
 - occipital condyle double
 - atlas = na₁ + ic₁
 - axis = c₁ + ic₂ + c₂ + na₂
 - **odontoid** process (dens) is c₁ + ic₂

- **RIBS**
 - arise from intersegmental mesoderm. Extend from vertebral column into the body wall.
- **FISH**
 - Many have two sets of ribs: ventral and dorsal.
 - Ventral ribs unite past the vent to form the hemal arches of the tail.
 - May have accessory processes = **epipleural**
- **TETRAPODS**
 - Most are **bicapital**
 - dorsal head (**tuberculum**)
 - ventral head (**capitulum**).
 - May have accessory processes = **uncinate**

- **STERNUM**
 - only in tetrapods and predominantly in amniotes.
 - **AMPHIBIANS**
 - highly variable from almost nonexistent (Apoda, Urodela) to complex (Anura)
 - **REPTILES**
 - also highly variable.
 - **BIRDS**
 - well developed for flight musculature with a well developed keel (**carina**).
 - **MAMMALS**
 - usually a series of bony segments known as **sternebrae**.

- **VERTEBRATE SKULL** (Chapter 9)
 - Can be defined to include 3 major sets of elements:
 1. **Neurocranium** –
 - Braincase (replacement bone)
 2. **Dermatocranium**
 - Dermal Skull Roof + Palatal Complex (mostly membrane bone)
 3. **Splanchnocranium**
 - Visceral Skeleton (replacement bone)

- **VERTEBRATE SKULL**

- Neurocranium :

- Function – protect brain and sense organs
- Originates entirely of cartilage.
- In higher forms is mostly replaced by bone.
- Development is similar in all jawed vertebrates (Fig. 9.2)
- 5 pairs of cartilage precursors
 - **Parachordal** – hindbrain
 - **Prechordal** – forebrain
 - **Olfactory capsule** – nasal region
 - **Otic capsule** – ear
 - **Optic capsule** – around eye (remains separate)

- **VERTEBRATE SKULL**

- All but the optic capsule grow together and form the base of the region housing the brain and sense organs
- Notochord and parachordal form **basal plate**
- Prechordals form **ethmoid plate**
- Lateral and dorsal (tectum) cartilage then forms to entirely surround the brain
- Remains relatively unchanged in Chondrichthyes as the **chondrocranium**

- **VERTEBRATE SKULL - Ossification**

- Begins in 4 specific regions.

1. Occipital centers – 4 distinct regions of ossification
 - **basioccipital**
 - **2 exoccipital**
 - **supraoccipital**
2. Sphenoid centers – midbrain ossifications beginning immediately in front of the basioccipital
 - **basisphenoid**
 - **presphenoid.**
 - **orbitosphenoid**

- **VERTEBRATE SKULL** - Ossification
 3. Ethmoid centers – remains as cartilage in most tetrapods.
 - **mesethmoid** in birds
 - **turbinal** bones form in birds and reptiles
 - **sphenethmoid** forms in frogs
 - **ethmoid** forming the **cribriform plate** separates the brain from the nasal passages in mammals
 4. Otic centers – surrounds the middle and inner ear
 - **prootic**
 - **opisthotic**
 - **periotic** (petrosal) which may fuse with the squamosal to form the **temporal**.

- **VERTEBRATE SKULL** - Dermatocranium
 - Originally part of the dermal armor of early vertebrates. Shield of solid dermal bones (scales) covering the top and sides of the head.
 - Modified in later forms for portions of the skull.
 - Has openings for: external nares, orbits, parietal foramen (pineal eye), spiracle or otic notch.
 - Typically divided into four regions
 - Roofing bones
 - Palatal Complex
 - Upper Jaw
 - Operculars

- **VERTEBRATE SKULL** - Dermatocranium
 - Roofing bones:
 - Rostral Series - variable elements in rostral region, usually reduced or modified in later forms
 - included **rostrils** and **postrostrils**
 - Paired Midline Series - paired elements on either side of the middorsal line
 - included: **prenasals, nasals, frontals, parietals, postparietals**
 - Circumorbital Ring - 5 bones surrounding the orbits
 - including: **prefrontal, postfrontal, postorbital, lacrimal, jugal**
 - Cheek Series
 - including: **squamosal, quadratojugal, preopercular** (lost in all except most primitive land vertebrates)
 - Tabular (Temporal) Series - skull table, formed the posterior part of the skull adjacent to the spiracular slit
 - included: **supratemporal, intertemporal, tabular**

- **VERTEBRATE SKULL** - Dermatocranium

- Upper Jaw:
 - Marginal Toothbearing Series
 - including: **maxillas**, **premaxillas**
- Opercular bones:
 - Extrascapulars - not part of skull proper, enlarged scales associated with the gills, have no homologs in tetrapods
 - included: **operculars**, **suboperculars**, **preopercular**, **interopercular**
- Palatal Complex - dermal bone + visceral skeletal ossifications
 - Dermal Bones:
 - **Parasphenoid**
 - Paired Elements (all may bear teeth)
 - **Pterygoids** (large), **Vomers**, **Palatines**, **Ectopterygoids**

- **VERTEBRATE SKULL**

- VISCERAL SKELETON (Splanchnocranium)
 - mesectodermally derived
 - skeleton of the gills and elements derived therefrom
 - encompasses:
 - upper jaw = **palatoquadrate** and its ossifications in the palatal complex
 - lower jaw = **mandibular cartilage** (Meckel's Cartilage) and its ossifications
 - middle ear bones of higher vertebrates
 - hyoid apparatus

- **VERTEBRATE SKULL**

- VISCERAL SKELETON (Splanchnocranium)
 - Ostracoderms
 - Each gill was supported by a gill bar consisting of 4 paired elements:
 - » **pharyngobranchial** - dorsal element
 - » **epibranchial**
 - » **ceratobranchial**
 - » **hypobranchial** - ventral element
 - **Basibranchial** joined the two sides together
 - These are the structures that gave rise to jaws

- **VERTEBRATE SKULL**

- **VISCERAL SKELETON** (Splanchnocranium)

- Mandibular Arch = Arch I
 - Epibranchial → Palatoquadrate
 - Ceratobranchial → Meckel's Cartilage
 - These cartilages then ossify to form parts of the upper and lower jaw
 - The endochondral elements are in turn covered with dermal elements (dermal sheathing bones)
 - Palatoquadrate → **quadrate** and **epipterygoid**
 - » Sheathing bones = **maxilla, premaxilla**
 - Meckel's Cartilage → **articular** bone
 - » Sheathing bones = **dentary, splenial, coronoids, angular, surangular**

- **VERTEBRATE SKULL**

- **VISCERAL SKELETON** (Splanchnocranium)

- Hyoid Arch = Arch II
 - In sharks consists of three cartilages:
 - » Basihyal = basibranchial
 - » Ceratohyal = ceratobranchial
 - » Hyomandibula = epibranchial
 - Homologous transitions:
 - Hyomandibula → symplectic → columella → stapes
 - Ceratohyal → symplectic → anterior horn of the hyoid → styloid process
 - Basihyal → body of the hyoid → entoglossus
