Chapter 6

The Skeletal System
Bone Function

- Support
- Protection
- Assist in movements
- Mineral homeostasis
- Blood cell production
  - Hemopoiesis in red bone marrow
- Triglyceride storage
Types of Bones

- Long bones: longer than wide
  - Such as thigh, leg, arm, forearm, fingers and toes
- Short bones: almost cube shaped
  - Most wrist and ankle bones
- Flat bones: thin and extensive surface
  - Such as cranial bones, sternum, ribs and scapulas
- Irregular bones: do not fit above categories
  - Such as vertebrae and some facial bones
Macroscopic Structure

Parts of a long bone

- Diaphysis: shaft of long bone; made up mostly of compact bone
- Epiphysis: broad end of long bone; mostly spongy bone
- Metaphysis: growth area between diaphysis and epiphysis
- Articular cartilage: hyaline cartilage at joint
- Periosteum: fibrous covering over most of bone
- Medullary cavity (marrow) with fat and blood cells
- Endosteum: membrane lining medullary cavity
Long Bones

- Proximal epiphysis
- Spongy bone
- Red bone marrow
- Epiphyseal line
- Endosteum (lines medullary cavity)
- Compact bone
- Periosteum
- Medullary cavity
- Nutrient artery in nutrient foramen
- Humerus
- Femur

Partially sectioned humerus (arm bone)
Long Bones

Proximal epiphysis

Spongy bone

Metaphysis

Compact bone

Medullary cavity in diaphysis

Longitudinally sectioned femur (thigh bone)
Microscopic Structure of Bone

- **Matrix**
  - 25% water, 25% collagen fibers, 50% mineral salts

- **Cells**
  - Osteogenic cells in periosteum →
  - Osteoblasts
    - Secrete collagen fibers
    - Build matrix and become trapped in lacunae
    - Become →
  - Osteocytes that maintain bone
  - Osteoclasts are formed from monocytes
    - Digest bone matrix for normal bone turnover
Histology of Bones

Osteogenic cell (develops into an osteoblast)

Osteoblast (forms bone extracellular matrix)

Osteocyte (maintains bone tissue)

Osteoclast (functions in resorption, the breakdown of bone matrix)

Types of cells in bone tissue
Compact Bone Structure

- Arranged in osteons (haversian systems)
  - Cylinders running parallel to long axis of bone
- Central canal through center of osteon
  - Contains blood vessels, nerves, lymphatics
- Concentric lamellae: layers of matrix
- Lacunae: “lakes” between lamellae
  - Contain osteocytes (bone cells)
Compact Bone Structure

- Canaliculi (“little canals”)
  - Contain extensions of osteocytes
  - Permit flow of ECF between central canal and lacunae

- Compact bone is covered by periosteum

- Perforating (Volkmann’s) canals
  - Carry blood and lymphatic vessels and nerves from periosteum
  - They supply central (Haversian) canals and also bone marrow
Histology of Bones

Central (haversian) canal
Lacuna with osteocyte
Concentric lamellae
Canaliculi

Sectional view of an osteon (haversian system)
Spongy Bone

- Not arranged in osteons
- Irregular latticework of trabeculae
  - These contain lacunae with osteocytes and canaliculi
- Spaces between trabeculae may contain red bone marrow
- Spongy bone is lighter than compact bone, so reduces weight of skeleton
Bone Dynamics and Tissue Interactions Animation

You must be connected to the internet to run this animation.
Bone Formation

- Known as ossification

- Timeline
  - Initial bone development in embryo and fetus
  - Growth of bone into adulthood
  - Remodeling: replacement of old bone
  - Repair if fractures occur

- Mesenchyme (early connective tissue) model
  - This initial “skeleton” model will be replaced by bone tissue beginning at 6 weeks of embryonic life
Bone Formation

- Two different methods of ossification each result in similar bone tissue
  - Intramembranous: bone forms within sheets of mesenchyme that resemble membranes
    - Only a few bones form by this process: flat bones of the skull, lower jawbone (mandible), and part of clavicle (collarbone)
  - Endochondrial: mesenchyme forms hyaline cartilage which then develops into bone
    - All other bones form by this process
Intramembranous Ossification

Four steps

1. Development of ossification center
   - Mesenchyme cells → osteogenic → osteoblasts
   - Osteoblasts secrete organic matrix

2. Calcification: cells become osteocytes
   - In lacunae they extend cytoplasmic processes to each other
   - Deposit calcium & other mineral salts

3. Formation of trabeculae (spongy bone)
   - Blood vessels grow in and red marrow is formed

4. Periosteum covering the bone forms from mesenchyme
1 Development of cartilage model
2 Growth of cartilage model
3 Development of primary ossification center
4 Development of the medullary cavity
5 Development of secondary ossification center
6 Formation of articular cartilage and epiphyseal plate
Endochondrial Ossification

Six Steps
1. Formation of cartilage model of the “bone”
   - As mesenchyme cells develop into chondroblasts
2. Growth of cartilage model
   - Cartilage “bone” grows as chondroblasts secrete cartilage matrix
   - Chondrocytes increase in size, matrix around them calcifies
   - Chondrocytes die as they are cut off from nutrients, leaving small spaces (lacunae)
Endochondral Ossification

Six Steps

3. Primary ossification center

- Perichondrium sends nutrient artery inwards into disintegrating cartilage
- Osteogenic cells in perichondrium become osteoblasts that deposit bony matrix over remnants of calcified cartilage → spongy bone forms in center of the model
- As perichondrium starts to form bone, the membrane is called periosteum
Endochondrial Ossification

Six Steps

4. Medullary (marrow) cavity
   - Spongy bone in center of the model grows towards ends of model
   - Osteoclasts break down some of new spongy bone forming a cavity (marrow) through most of diaphysis
   - Most of the wall of the diaphysis is replaced by a collar of compact bone
### Six Steps

5. Secondary ossification center
   - Similar to step 3 except that nutrient arteries enter ends (epiphyses) of bones and osteoblasts deposit bony matrix $\rightarrow$ spongy bone forms in epiphyses from center outwards
   - Occurs about time of birth

6. Articular cartilage and epiphyseal cartilage
   - Articular cartilage at ends of epiphyses becomes articular cartilage
   - Epiphyseal (growth) plate of cartilage remains between epiphysis and diaphysis until bone growth ceases
Growth in Length

- Chondrocytes divide and grow more cartilage on epiphyseal side of the epiphyseal plate
- Chondrocytes on the diaphyseal side die and are replaced by bone
- Therefore bone grows from diaphyseal side towards epiphyseal side
- Growth in length stops between 18-25 years; cartilage in epiphyseal plate is completely replaced by bone (epiphyseal line)
Growth in Thickness

- As bones grow in length, they must also grow in thickness (width)
  - Perichondrial osteoblasts $\rightarrow$ osteoblasts $\rightarrow$ lay down additional lamellae of compact bone
  - Simultaneously, osteoclasts in the endosteum destroy interior bone to increase width of the marrow
Remodeling and Repair

- Remodeling in response to use
  - Resorption by osteoclasts and
  - Deposition by osteoblasts
- Repair after a fracture
  - Dead tissue removed
  - Chondroblasts $\rightarrow$ fibrocartilage $\rightarrow$ spongy bone deposited by osteoblasts $\rightarrow$ remodeled to compact bone
Types of Fractures

- Partial: incomplete break (crack)
- Complete: bone broken into two or more pieces
- Closed (simple): not through skin
- Open (compound): broken ends break skin
Factors Affecting Growth

- Adequate minerals (Ca, P, Mg)
- Vitamins A, C, D
- Hormones
  - Before puberty: hGH + insulin-like growth factors
  - Thyroid hormone and insulin also required
  - Sex hormones contribute to adolescent growth spurt
- Weight-bearing activity
Calcium Homeostasis

- Blood levels of Ca\(^{2+}\) controlled
- Negative feedback loops
- Parathyroid hormone (PTH) \(\rightarrow\) increases osteoclast activity + decreases loss of Ca\(^{2+}\) in urine
- Calcitonin \(\rightarrow\) decreases osteoclast activity
Negative Feedback

Some stimulus disrupts homeostasis by decreasing blood calcium (Ca^{2+}) level.

Input

Decreasing blood calcium (Ca^{2+}) level.

Receptors

Parathyroid gland cells detect lowered Ca^{2+} level.

Control center

Increased production of cyclic AMP.

Output

Increased release of PTH.

Effectors

Osteoclasts: Increase bone resorption.

Kidneys: Retain Ca^{2+} in blood and produce calcitriol.

Increase in blood Ca^{2+} level.

Return to homeostasis when response brings blood Ca^{2+} level back to normal.
Exercise & Bone Tissue

- Bone strengthened in response to use
- Bone resorbed during disuse; examples:
  - During prolonged bed rest
  - Fracture with cast/immobilizer
  - Astronauts without gravity
Divisions of Skeletal System

- Two divisions: axial and appendicular
  - Axial: bones around body axis
    - Examples: skull bones, hyoid, ribs, sternum, vertebrae
  - Appendicular: bones of upper and lower limbs plus shoulder and hip bones that connect them
    - Examples: collar bone (clavicle), arm (humerus), forearm (radius and ulna), thigh bone (femur)
Divisions of the Skeletal System
Skull & Hyoid Bone

- Eight Cranial bones
  - Frontal, 2 parietal, 2 temporal, occipital, sphenoid, and ethmoid

- Fourteen Facial bones
  - 2 nasal, 2 maxilla, 2 zygomatic, 2 lacrimal
  - 2 palatine, 2 inferior nasal conchae, 1 mandible, 1 vomer
Skull

Coronal suture
PARIETAL BONE
Squamous suture
TEMPORAL BONE
Lambdoid suture
Mandibular fossa
OCCIPITAL BONE
External auditory meatus
Mastoid process
Foramen magnum
Styloid process
FRONTAL BONE
SPHENOID BONE
ETHMOID BONE
NASAL BONE
LACRIMAL BONE
Zygomatic arch
ZYGOMATIC BONE
Condylar process of mandible
MAXILLA
Mental foramen
MANDIBLE

Right lateral view
Skull

Inferior view, mandible removed

View

MAXILLA

ZYGOMATIC BONE

Zygomatic arch

VOMER

Foramen ovale

Mandibular fossa

Carotid foramen

Jugular foramen

Occipital condyle

TEMPORAL BONE

OCCIPITAL BONE

PALATINE BONE

Middle nasal concha

SPHENOID BONE

Styloid process

Mastoid process

Foramen magnum

PARIETAL BONE

Lambdoid suture

Incisor teeth
Sphenoid Bone

- FRONTAL BONE
- ETHMOID BONE: Crista galli, Olfactory foramina, Cribriform plate
- SPHENOID BONE: Optic foramen, Hypophyseal fossa
- TEMPORAL BONE: Squamous suture, Jugular foramen
- PARIETAL BONE
- OCCIPITAL BONE: Lambdoid suture

Superior view of floor of cranium
Ethmoid Bone

- Olfactory foramina
- Ethmoidal cells of ethmoidal sinus
- Lateral mass
- Cribriform plate
- Crista galli
- Perpendicular plate

ANTERIOR
 Superior view

POSTERIOR

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Unique Features of Skull

- Sutures: immovable joint between skull bones
  - Coronal, sagittal, lambdoidal, squamous
- Paranasal sinuses: cavities
  - Located in bones near nasal cavity
- Fontanelles: soft spot in fetal skull
  - Allow deformation at birth
  - Calcify to form sutures
Paranasal Sinuses

- Frontal sinus
- Ethmoidal cells of ethmoidal sinus
- Sphenoidal sinus
- Maxillary sinus

Right lateral view
Vertebrae

■ Functions
  - Encloses spinal cord
  - Supports head
  - Point of attachment for muscles of back, ribs and pelvic girdle

■ Regions (from superior to inferior)
  - 7 cervical
  - 12 thoracic
  - 5 lumbar
  - 1 sacrum and 1 coccyx
Normal Curves in Column

- Four normal curves
  - Cervical and lumbar curves are convex (bulge anteriorly)
  - Thoracic and sacral curves are concave (bulge posteriorly)
- Curves increase strength, help in balance and absorb shocks
Vertebral Column

Right lateral view showing four normal curves

Cervical curve (formed by 7 cervical vertebrae)
Thoracic curve (formed by 12 thoracic vertebrae)
Lumbar curve (formed by 5 lumbar vertebrae)
Sacral curve (formed by 5 fused sacral vertebrae)

Intervertebral disc
Intervertebral foramen
Sacrum
Coccyx
Vertebral Column

- Single curve in fetus
- Four curves in adult
- Fetal and adult curves
Structure of Vertebra

- Body: disc-shaped anterior portion
- Vertebral arch: posteriorly back from body
  - With the body, creates a hole called vertebral foramen
- Seven processes from this arch
  - Transverse process extending laterally on each side
  - Spinous process extending dorsally
  - Two each of superior and inferior articular processes that form joints with vertebrae
Structure of Vertebra

(a) Superior view

(b) Right posterolateral view

ANTERIOR
Location of thoracic vertebrae

POSTERIOR
Spinal cord
Facet of superior articular process
Pedicle
Spinous process
Transverse process
Vertebral arch:
Lamina
Pedicle
Facet for rib
Body
Vertebral foramen

Spinal nerve
Intervertebral disc
Intervertebral foramen
Facets for rib
Body
Inferior articular process

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Cervical Area

- Cervical (C1-C7 from superior to inferior)
  - Spinous process often bifid with transverse foramina on transverse processes

- C1: atlas
  - Articulates with head, specialized to support head
  - Lacks body and spinous process

- C2: axis
  - Has body and spinous process
  - Called dens ("tooth") that creates a pivot for head rotation
Cervical Vertebrae
Other Vertebrae

- Thoracic (T1-T12)
  - Larger than cervical
  - Have facets for articulations with ribs

- Lumbar (L1-L5)
  - Largest and strongest; spinous processes short and thick

- Sacrum (S1-S5 fused into one unit)
  - Foundation for pelvic girdle
  - Contain sacral foramina for nerves and blood vessels

- Coccyx: 4 coccygeal vertebrae fused into 1
Lumbar Vertebrae

- POSTERIOR
  - Spinous process
  - Superior articular facet
  - Transverse process
  - Vertebral foramen
- ANTERIOR
  - Lamina
  - Pedicle
  - Body

Location of lumbar vertebrae

Superior view
Sacrum and Coccyx

(a) Anterior view

(b) Posterior view

Location of sacrum and coccyx

Sacral promontory

Sacral foramen

Superior articular process

Superior articular facet

Sacral canal

Sacral foramen

Sacrum

Sacral hiatus

Coccyx

Co 1
Co 2
Co 3
Co 4

S1
S2
S3
S4
S5
Thorax

- Thoracic cage: sternum, costal cartilages, ribs and bodies of T1-T12
- Sternum: form by 3 portions fused by about age 25 years:
  - Manubrium, body, xiphoid process
- Ribs: 12 pairs
- True ribs are #1-7: articulate with sternum directly by costal cartilages
- False ribs are #8-12: do not articulate with sternum directly by costal cartilages
Pectoral Girdle

- Function: attach bones of upper limbs to axial skeleton
- Clavicles and scapulas: bilateral
Right Pectoral (Shoulder) Girdle

(a) Anterior view
(b) Posterior view

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Upper Limb

- Humerus: arm bone
  - Articulates with scapula (glenoid cavity) at shoulder joint
  - Articulates with radius and ulna at elbow
- Ulna: medial bone
- Radius: lateral bone (thumb side)
Right Humerus

- Head
- Anatomical neck
- Surgical neck
- Scapula
- HUMERUS
- Deltoid tuberosity
- Body
- Radial fossa
- Capitulum
- Coronoid fossa
- Trochlea
- Olecranon fossa
- Ulna
- Radius

Anterior view

Posterior view

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Right Ulna and Radius

View
Radius
Ulna

Olecranon

Trochlear notch
Coronoid process
Radial notch

Lateral view of proximal end of ulna
Wrist and Hand

- **Carpus (wrist):** 8 bones
- **Metacarpals:** 5 bones of palm of hand
  - Number 1-5 starting with thumb
- **Phalanges:** 14 bones of fingers
  - Numbered 1-5 metacarpals
  - Each finger except the thumb has proximal, middle and distal phalanges; thumb lacks middle phalanx
Right Wrist and Hand
Pelvic (Hip) Girdle

- Pelvic girdle includes two hip (coxal) bones
  - Joined anteriorly at pubic symphysis
  - Posteriorly attached to sacrum at sacroiliac joint

- Basin-like pelvis is formed by two hip bones (pelvic girdle) + sacrum and coccyx
  - False (greater) pelvis: broad region superior to pelvic brim; contains abdominal organs
  - True (lesser) pelvis: small region inferior to pelvic brim; contains urinary bladder + internal reproductive organs
Pelvic Girdle (Female)

- Greater (false) pelvis
- Iliac crest
- Sacroiliac joint
- Sacrum
- Pelvic brim
- Coccyx
- Acetabulum
- Obturator foramen
- Pubic symphysis

Anterior view
Pelvic Girdle (Female)

Midsagittal plane

Sacrum

True pelvis

Coccyx

Plane of pelvic outlet

False pelvis

Plane of pelvic brim

Pelvic axis

Pubic symphysis

Midsagittal section indicating locations of true and false pelves

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Parts of Each Hip (Coxal) Bone

- 3 separate bones fuse by age 23 to form a hip bone
  - Ilium: largest and most superior
  - Ischium: lower posterior part
  - Pubis: lower anterior part
- Bones meet at the acetabulum of the hip bone (socket for head of femur)
Lower Limb

- Femur (thigh bone): largest bone in the body
  - Articulates with hip proximally and with the tibia and patella distally
  - Head (fits into acetabulum) and greater trochanter at proximal end

- Patella: kneecap in anterior of knee joint

- Tibia: shin bone
  - Large medial, weight-bearing bone of leg

- Fibula: longest, thinnest bone in body
  - Lateral to tibia and smaller
  - Does not articulate with femur
Right Femur
Right Tibia and Fibula
Ankle and Foot

- Tarsus (ankle) has 7 bones
  - Large talus (ankle bone) and
  - Calcaneus (heel bone)
- Metatarsals (foot bones)
  - Numbered 1 to 5 from medial to lateral
- Phalanges (toe bones)
  - Big toe has proximal and distal phalanges while others have proximal, medial and distal phalanges. Numbered like metatarsals from 1-5
Right Foot
Arches of the Right Foot

- Lateral malleolus of fibula
- MEDIAL PART OF LONGITUDINAL ARCH
- Cuboid
- Calcaneus
- Talus
- Navicular
- Cuneiforms
- Metatarsals

TRANVERSE ARCH

LATERAL PART OF LONGITUDINAL ARCH

Lateral view
Male and Female Differences

- Males usually have heavier bones
- Related to muscle size and strength
- Female pelvis is wider and shallower than male pelvis: allows for birth
Aging and Skeletal System

- Birth through adolescence: more bone formed than lost
- Young adults: gain and loss about equal
- As levels of sex steroids decline with age: bone resorption > bone formation
- Bones become brittle and lose calcium
Osteoporosis

(a) Normal bone

(b) Osteoporotic bone