Chapter 6: Tissue: Bones and Skeletal Tissues

Objectives:
1. Describe the functional properties of the three types of cartilage tissue.
2. Locate the major cartilages of the adult skeleton.
3. Explain how cartilage grows.
4. Name the major regions of the skeleton and describe their relative functions.
5. Compare and contrast the structure of the four bone classes and provide examples of each class.
6. List and describe five important functions of bone.
7. Describe the gross anatomy of a typical long bone and a flat bone. Indicate the locations and functions of red and yellow marrow, articular cartilage, periosteum and endosteum.
8. Indicate the functional importance of bone markings.
9. Describe the histology of compact and spongy bone.
10. Discuss the chemical composition of bone and the relative advantages conferred by the organic and inorganic components.
11. Compare and contrast intramembranous ossification and endochondral ossification.
12. Describe the process of long bone growth that occurs at the epiphyseal plates.
13. Compare the locations and remodeling functions of the osteoblasts, osteocytes and osteoclasts.
14. Explain how hormones and physical stress regulate bone remodeling.
15. Describe the steps of fracture repair.
16. Contrast the disorders of bone remodeling seen in osteoporosis, osteomalacia and Paget’s disease.
17. Describe the timing and cause of changes in bone architecture and bone mass throughout life.

I. Skeletal Cartilage
   A. Basic Structure, Types and Locations
      1. Contains no blood vessels or nerves
      2. Surrounded by the perichondrium (dense irregular connective tissue) that resists outward expansion
      3. Three types
         a. hyaline
b. elastic  
c. fibrocartilage  

B. Hyaline Cartilage  
1. Provides support, flexibility, and resilience  
2. Is the most abundant skeletal cartilage  
3. Is present in these cartilages:  
   a. Articular – covers the ends of long bones  
   b. Costal – connects the ribs to the sternum  
   c. Respiratory – makes up larynx, reinforces air passages  
   d. Nasal – supports the nose  

C. Elastic Cartilage  
1. Similar to hyaline cartilage, but contains elastic fibers  
2. Found in the external ear and the epiglottis  

D. Fibrocartilage  
1. Highly compressed with great tensile strength  
2. Contains collagen fibers  
3. Found in  
   a. menisci of the knee  
   b. intervertebral discs  

E. Growth of Cartilage  
1. Appositional  
   a. cells in the perichondrium secrete matrix against the external  
      face of existing cartilage  
2. Interstitial  
   a. lacunae-bound chondrocytes inside the cartilage divide and  
      secrete new matrix, expanding the cartilage from within  
3. Calcification of cartilage occurs  
   a. During normal bone growth  
   b. During old age  

II. Classification of Bone  
A. Axial skeleton  
   1. skull  
   2. vertebral column  
   3. rib cage  

B. Appendicular skeleton  
   1. upper and lower limbs  
   2. shoulder  
   3. hip
III. Classification of Bone by Shape
   A. Long bones
      1. longer than they are wide
      2. e.g., humerus
   B. Short bones
      1. Cube-shaped bones of the wrist and ankle
      2. Bones that form within tendons
      3. e.g., patella
   C. Flat bones
      1. thin, flattened, and a bit curved
      2. e.g., sternum, and most skull bones
   D. Irregular bones
      1. bones with complicated shapes
      2. e.g., vertebrae and hip bones

IV. Function of Bones
   A. Support
      1. form the framework that supports the body and cradles soft organs
   B. Protection
      1. provide a protective case for the brain, spinal cord, and vital organs
   C. Movement
      1. provide levers for muscles
   D. Mineral storage
      1. reservoir for minerals
         a. calcium
         b. phosphorus
   E. Blood cell formation
      1. hematopoiesis occurs within the marrow cavities of bones

V. Bone Structure
   A. Gross Anatomy
      1. Bone Markings
         a. Bulges, depressions, and holes that serve as:
            1) Sites of attachment for muscles, ligaments, and tendons
            2) Joint surfaces
            3) Conduits for blood vessels and nerves
      2. Projections
         a. Tuberosity - rounded projection
b. Crest – narrow, prominent ridge of bone
c. Trochanter – large, blunt, irregular surface
d. Line – narrow ridge of bone
e. Tubercle – small rounded projection
f. Epicondyle – raised area above a condyle
g. Spine – sharp, slender projection
h. Process – any bony prominence
i. Head – bony expansion carried on a narrow neck
j. Facet – smooth, nearly flat articular surface
k. Condyle – rounded articular projection
l. Ramus – armlike bar of bone

3. Depressions and Openings
   a. Meatus – canal-like passageway
   b. Sinus – cavity within a bone
   c. Fossa – shallow, basin-like depression
   d. Groove – furrow
   e. Fissure – narrow, slit-like opening
   f. Foramen – round or oval opening through a bone

4. Bone Textures
   a. Compact bone – dense outer layer
   b. Spongy bone – honeycomb of trabeculae filled with yellow bone marrow

B. Structure of a Long Bone
   1. Long bones consist of a diaphysis and an epiphysis
   2. Diaphysis
      a. Tubular shaft that forms the axis of long bones
      b. Composed of compact bone that surrounds the medullary cavity
      c. Yellow bone marrow (fat) is contained in the medullary cavity
   3. Epiphyses
      a. Expanded ends of long bones
      b. Exterior is compact bone, and the interior is spongy bone
      c. Joint surface is covered with articular (hyaline) cartilage
      d. Epiphyseal line separates the diaphysis from the epiphyses

C. Bone Membranes
   1. Periosteum – double-layered protective membrane
      a. Outer fibrous layer is dense regular connective tissue
      b. Inner osteogenic layer is composed of osteoblasts and osteoclasts
c. Richly supplied with nerve fibers, blood, and lymphatic vessels, which enter the bone via nutrient foramina
d. Secured to underlying bone by Sharpey’s fibers

2. Endosteum – delicate membrane covering internal surfaces of bone

D. Structure of Short, Irregular, and Flat Bones
1. Thin plates of periosteum-covered compact bone on the outside with endosteum-covered spongy bone (diploë) on the inside
2. Have no diaphysis or epiphyses
3. Contain bone marrow between the trabeculae

E. Location of Hematopoietic Tissue (Red Marrow)
1. In infants
   a. Found in the medullary cavity and all areas of spongy bone
2. In adults
   a. Found in the diploë of flat bones, and the head of the femur and humerus

F. Microscopic Structure of Bone: Compact Bone
1. Haversian system, or osteon – the structural unit of compact bone
2. Lamella – weight-bearing, column-like matrix tubes composed mainly of collagen
3. Haversian, or central canal – central channel containing blood vessels and nerves
4. Volkmann’s canals – channels lying at right angles to the central canal, connecting blood and nerve supply of the periosteum to that of the Haversian canal
5. Osteocytes – mature bone cells
6. Lacunae – small cavities in bone that contain osteocytes
7. Canaliculi – hairlike canals that connect lacunae to each other and the central canal

G. Chemical Composition of Bone: Organic
1. Osteoblasts – bone-forming cells
2. Osteocytes – mature bone cells
3. Osteoclasts – large cells that resorb or break down bone matrix
4. Osteoid – unmineralized bone matrix composed of proteoglycans, glycoproteins, and collagen

H. Chemical Composition of Bone: Inorganic
1. mineral salts
2. Sixty-five percent of bone by mass
3. Mainly calcium phosphates
4. Responsible for bone hardness and its resistance to compression

VI. Bone Development
A. Osteogenesis and ossification – the process of bone tissue formation, which leads to:
   1. The formation of the bony skeleton in embryos
   2. Bone growth until early adulthood
   3. Bone thickness, remodeling, and repair
B. Formation of the Bony Skeleton
   1. Begins at week 8 of embryo development
   2. Intramembranous ossification – bone develops from a fibrous membrane
   3. Endochondral ossification – bone forms by replacing hyaline cartilage
C. Intramembranous Ossification
   1. Formation of most of the flat bones of the skull and the clavicles
   2. Fibrous connective tissue membranes are formed by mesenchymal cells
   3. Endochondral Ossification
      1. Begins in the second month of development
      2. Uses hyaline cartilage “bones” as models for bone construction
      3. Requires breakdown of hyaline cartilage prior to ossification
D. Postnatal Bone Growth
   1. Growth in length of long bones
   2. Cartilage on the side of the epiphyseal plate closest to the epiphysis is relatively inactive
   3. Cartilage abutting the shaft of the bone organizes into a pattern that allows fast, efficient growth
   4. Functional Zones in Long Bone Growth
      a. Growth zone – cartilage cells undergo mitosis, pushing the epiphysis away from the diaphysis
      b. Transformation zone – older cells enlarge, the matrix becomes calcified, cartilage cells die, and the matrix begins to deteriorate
      c. Osteogenic zone – new bone formation occurs
E. Long Bone Growth and Remodeling
   1. Growth in length – cartilage continually grows and is replaced by bone as shown
   2. Remodeling – bone is resorbed and added by appositional growth
F. Hormonal Regulation of Bone Growth During Youth
   1. During infancy and childhood, epiphyseal plate activity is stimulated by growth hormone
   2. During puberty, testosterone and estrogens:
      a. Initially promote adolescent growth spurts
      b. Cause masculinization and feminization of specific parts of the skeleton
      c. Later induce epiphyseal plate closure, ending longitudinal bone growth

G. Bone Remodeling
   1. Remodeling units – adjacent osteoblasts and osteoclasts deposit and resorb bone at periosteal and endosteal surfaces

H. Bone Deposition
   1. Occurs where bone is injured or added strength is needed
   2. Requires a diet rich in protein, vitamins C, D, and A, calcium, phosphorus, magnesium, and manganese

I. Bone Resorption
   1. Accomplished by osteoclasts
   2. Resorption involves osteoclast secretion of:
      a. Lysosomal enzymes that digest organic matrix
      b. Acids that convert calcium salts into soluble forms
      c. Dissolved matrix is transcytosed across the osteoclast’s cell where it is secreted into the interstitial fluid and then into the blood

J. Importance of Ionic Calcium in the Body
   1. Calcium is necessary for:
      a. Transmission of nerve impulses
      b. Muscle contraction
      c. Blood coagulation
      d. Secretion by glands and nerve cells
      e. Cell division

K. Control of Remodeling
   1. Two control loops regulate bone remodeling
   2. Hormonal mechanism maintains calcium homeostasis in the blood
   3. Mechanical and gravitational forces acting on the skeleton
   4. Hormonal Mechanism
      a. Rising blood Ca^{2+} levels trigger the thyroid to release calcitonin
      b. Calcitonin stimulates calcium salt deposit in bone
c. Falling blood Ca\(^{2+}\) levels signal the parathyroid glands to release PTH
d. PTH signals osteoclasts to degrade bone matrix and release Ca\(^{2+}\) into the blood

VII. Bone Fractures (Breaks)
A. Bone fractures are classified by:
   1. The position of the bone ends after fracture
   2. The completeness of the break
   3. The orientation of the bone to the long axis
   4. Whether or not the bones ends penetrate the skin
B. Types of Bone Fractures
   1. Nondisplaced – bone ends retain their normal position
   2. Displaced – bone ends are out of normal alignment
   3. Complete – bone is broken all the way through
   4. Incomplete – bone is not broken all the way through
   5. Linear – the fracture is parallel to the long axis of the bone
   6. Transverse – the fracture is perpendicular to the long axis of the bone
   7. Compound (open) – bone ends penetrate the skin
   8. Simple (closed) – bone ends do not penetrate the skin
   9. Comminuted – bone fragments into three or more pieces; common in the elderly
   10. Spiral – ragged break when bone is excessively twisted; common sports injury
   11. Depressed – broken bone portion pressed inward; typical skull fracture
   12. Compression – bone is crushed; common in porous bones
   13. Epiphyseal – epiphysis separates from diaphysis along epiphyseal line; occurs where cartilage cells are dying
   14. Greenstick – incomplete fracture where one side of the bone breaks and the other side bends; common in children

VII. Homeostatic Imbalances
A. Osteomalacia
   1. Bones are inadequately mineralized causing softened, weakened bones
   2. Main symptom is pain when weight is put on the affected bone
   3. Caused by insufficient calcium in the diet, or by vitamin D deficiency
B. Rickets
1. Bones of children are inadequately mineralized causing softened, weakened bones
2. Bowed legs and deformities of the pelvis, skull, and rib cage are common
3. Caused by insufficient calcium in the diet, or by vitamin D deficiency

C. Osteoporosis
1. Group of diseases in which bone reabsorption outpaces bone deposit
2. Spongy bone of the spine is most vulnerable
3. Occurs most often in postmenopausal women
4. Bones become so fragile that sneezing or stepping off a curb can cause fractures
5. Treatment
   a. Calcium and vitamin D supplements
   b. Increased weight-bearing exercise
   c. Hormone (estrogen) replacement therapy (HRT) slows bone loss

D. Paget’s Disease
1. Characterized by excessive bone formation and breakdown
2. Pagetic bone with an excessively high ratio of woven to compact bone is formed
3. Pagetic bone, along with reduced mineralization, causes spotty weakening of bone
4. Osteoclast activity wanes, but osteoblast activity continues to work
5. Usually localized in the spine, pelvis, femur, and skull
6. Unknown cause (possibly viral)
7. Treatment includes the drugs Didronate and Fosamax

IX. Developmental Aspects of Bones
A. Mesoderm gives rise to embryonic mesenchymal cells, which produce membranes and cartilages that form the embryonic skeleton
B. The embryonic skeleton ossifies in a predictable timetable that allows fetal age to be easily determined from sonograms
C. At birth, most long bones are well ossified (except for their epiphyses)
D. By age 25, nearly all bones are completely ossified
E. In old age, bone resorption predominates
F. A single gene that codes for vitamin D docking determines both the tendency to accumulate bone mass early in life, and the risk for osteoporosis later in life