Chapter 7

The Skeletal System: Bone Tissue

INTRODUCTION

• Bone is made up of several different tissues working together: bone tissue, cartilage, dense connective tissue, epithelium, blood forming tissues, adipose tissue, and nervous tissue
• Each individual bone is an organ
• Dynamic and ever-changing throughout life
• The bones, along with their cartilages, make up the skeletal system

Functions of Bone

• Supporting & protecting soft tissues
• Attachment site for muscles making movement possible
• Storage of the minerals, calcium & phosphate -- mineral homeostasis
• Blood cell production occurs in red bone marrow (hemopoiesis)
• Energy storage in yellow bone marrow

Anatomy of a Long Bone

• diaphysis = shaft
• epiphysis = one end of a long bone
• metaphyses are the areas between the epiphysis and diaphysis and include the epiphyseal plate in growing bones.
• Articular cartilage over joint surfaces acts as friction reducer & shock absorber
• Medullary cavity = marrow cavity
Anatomy of a Long Bone

- **Endosteum** = lining of marrow cavity
- **Periosteum** = tough membrane covering bone but not the cartilage
  - fibrous layer = dense irregular CT
  - osteogenic layer = bone cells & blood vessels that nourish or help with repairs

Histology of Bone

- A type of connective tissue as seen by widely spaced cells separated by matrix
- Matrix of 25% water, 25% collagen fibers & 50% crystalized mineral salts
- 4 types of cells in bone tissue

Histology of Bone Tissue

- **Bone (osseous) tissue** consists of widely separated cells surrounded by large amounts of matrix.
- The matrix of bone contains inorganic salts, primarily hydroxyapatite and some calcium carbonate, and collagen fibers.
- These and a few other salts are deposited in a framework of collagen fibers, by a process called **calcification**.
  - The process of calcification occurs only in the presence of collagen fibers.
  - Mineral salts confer hardness on bone while collagen fibers give bone its great tensile strength.

Four Types of Bone Cells

- Osteoprogenitor (osteogenic) cells -- undifferentiated cells
  - can divide to replace themselves & can become osteoblasts
  - found in inner layer of periosteum and endosteum
- Osteoblasts -- form matrix & collagen fibers but can’t divide
- Osteocytes -- the principal cells of bone tissue.
  - mature cells that no longer secrete matrix
- Osteoclasts -- huge cells from fused monocytes (WBC)
  - serve to break down bone tissue
  - function in bone resorption at surfaces such as endosteum
Matrix of Bone

- Inorganic mineral salts provide bone’s hardness
  - hydroxyapatite (calcium phosphate) & calcium carbonate
- Organic collagen fibers provide bone’s flexibility
  - their tensile strength resists being stretched or torn
- Remove minerals with acid & rubbery structure results
- Denature collagen by heating and bones become brittle
- Bone is not completely solid since it has small spaces for vessels and red bone marrow
  - spongy bone has many such spaces
  - compact bone has very few such spaces

Compact Bone

- *Compact bone* is arranged in units called *osteons* or *Haversian systems*
- Osteons contain blood vessels, lymphatic vessels, nerves, and osteocytes along with the calcified matrix.
- Osteons are aligned in the same direction along lines of stress. These lines can slowly change as the stresses on the bone changes.

Histology of Compact Bone

- Osteon is concentric rings (lamellae) of calcified matrix surrounding a vertically oriented blood vessel
- Osteocytes are found in spaces called lacunae
- Osteocytes communicate through canaliculi filled with extracellular fluid that connect one cell to the next cell

Compact or Dense Bone

- Looks like solid hard layer of bone
- Makes up the shaft of long bones and the external layer of all bones
- Resists stresses produced by weight and movement
Spongy Bone

- Spongy (cancellous) bone does not contain osteons. It consists of trabeculae surrounding many red marrow filled spaces
- It forms most of the structure of short, flat, and irregular bones, and the epiphyses of long bones
- Spongy bone tissue is light and supports and protects the red bone marrow

The Trabeculae of Spongy Bone

- Latticework of thin plates of bone called trabeculae oriented along lines of stress
- Spaces in between these struts are filled with red marrow where blood cells develop

Blood Supply of Bone

- Periosteal arteries
  - supply periosteum
- Nutrient arteries
  - enter through nutrient foramen
  - supplies compact bone of diaphysis & red marrow
- Metaphyseal & epiphyseal arteries
  - supply red marrow & bone tissue of epiphyses

BONE FORMATION

- All embryonic connective tissue begins as mesenchyme
- Bone formation is termed osteogenesis or ossification
- Two types of ossification occur
  - Intramembranous ossification is the formation of bone directly from fibrous connective tissue membranes (dermis)
  - Endochondral ossification is the formation of bone from hyaline cartilage models
Intramembranous Bone Formation

- Intramembranous ossification forms the flat bones of the skull and the mandible
  - An ossification center forms from mesenchymal cells as they convert to osteoblasts and lay down osteoid matrix.
  - The matrix surrounds the cell and then calcifies as the osteoblast becomes an osteocyte.
  - The calcifying matrix centers join to form bridges of trabeculae that constitute spongy bone with red marrow between.
  - On the periphery the mesenchyme condenses and develops into the periosteum.

Endochondral Bone Formation

- *Endochondral ossification* involves replacement of cartilage by bone and forms most of the bones of the body
- The first step in endochondral ossification is the development of the *cartilage model*

Endochondral Bone Formation

- Development and Growth of Cartilage Model
  - mesenchymal cells form a cartilage model
  - interstitial growth in length occurs by chondrocyte cell division and matrix formation
  - appositional growth in width occurs by formation of new matrix on the periphery by new chondroblasts from the perichondrium
  - cells in midregion burst and change pH triggering calcification and chondrocyte death
Endochondral Bone Formation

- Development of Primary Ossification Center
  - nutrient artery penetrates center of cartilage model
  - cells in perichondrium differentiate into osteoblasts and start forming bone
  - osteoblasts and osteoclasts migrate to center of cartilage model
  - osteoblasts deposit bone matrix over calcified cartilage forming spongy bone trabeculae
  - Osteoclasts form medullary cavity

Bone Growth in Length

- Bones grow in length at the epiphyseal (growth) plate
- The *epiphyseal plate* consists of four zones:
  - zone of resting cartilage
  - zone of proliferating cartilage
  - zone of hypertrophic cartilage
  - zone of calcified cartilage
- Activity at the epiphyseal plate is the only means by which the diaphysis can increase in length

Endochondral Bone Formation

- Development of Secondary Ossification Center
  - blood vessels enter the epiphyses around time of birth
  - spongy bone is formed but no medullary cavity
  - cartilage on ends of bone remains as articular cartilage

Zones of Growth in Epiphyseal Plate

- Zone of resting cartilage
  - anchors growth plate to bone
- Zone of proliferating cartilage
  - rapid cell division (stacked coins)
- Zone of hypertrophic cartilage
  - cells enlarged & remain in columns
- Zone of calcified cartilage
  - thin zone, cells mostly dead since matrix calcified
  - osteoclasts removing matrix
  - osteoblasts & capillaries move in to create bone over calcified cartilage
Bone Growth in Length

- Between ages 18 to 25, epiphyseal plates close
  - cartilage cells stop dividing and bone replaces the cartilage (epiphyseal line)
- Growth in length stops by age 25

Factors Affecting Bone Growth

- Nutrition
  - adequate levels of minerals and vitamins
    - calcium and phosphorus for bone growth
    - vitamin C for collagen formation
    - vitamins K and B12 for protein synthesis
- Sufficient levels of specific hormones
  - during childhood need insulin-like growth factor
    - promotes cell division at epiphyseal plate
    - need hGH (growth), thyroid (T3 & T4) and insulin
  - at puberty the sex hormones, estrogen and testosterone, stimulate sudden growth and modifications of the skeleton to create the male and female forms

Bone Growth in Thickness

- Only by appositional growth at the bone’s surface
- Periosteal cells differentiate into osteoblasts and form bony ridges and then a tunnel around periosteal blood vessel
- Concentric lamellae fill in the tunnel to form an osteon

Hormonal Abnormalities

- Oversecretion of hGH (human growth hormone) during childhood produces gigantism
- Undersecretion of hGH or thyroid hormone during childhood produces dwarfism
- Both men or women that lack estrogen receptors on cells grow taller than normal
  - estrogen is responsible for closure of growth plate
Bone Remodeling

- *Remodeling* is the ongoing replacement of old bone tissue by new bone tissue
  - Old bone is constantly destroyed by osteoclasts, whereas new bone is constructed by osteoblasts
  - In orthodontics teeth are moved by braces. This places stress on bone in the sockets causing osteoclasts and osteoblasts to remodel the sockets so that the teeth can be properly aligned
  - Several hormones and calcitriol control bone growth and bone remodeling

Bone Remodeling

- Ongoing since osteoclasts carve out small tunnels and osteoblasts rebuild osteons.
  - osteoclasts form leak-proof seal around cell edges
  - secrete enzymes and acids beneath themselves
  - release calcium and phosphorus into interstitial fluid
  - osteoblasts take over bone rebuilding
- Continual redistribution of bone matrix along lines of mechanical stress
  - distal femur is fully remodeled every 4 months

Fracture & Repair of Bone

- A *fracture* is any break in a bone
- Healing is faster in bone than in cartilage due to lack of blood vessels in cartilage
- Healing of bone is still slow process due to vessel damage
- Clinical treatment
  - closed reduction = restore pieces to normal position by manipulation
  - open reduction = realignment during surgery

Fractures

- Named for shape or position of fracture line
- Common types of fracture
  - greenstick -- partial fracture
  - impacted -- one side of fracture driven into the interior of other side
Fractures

- Common types of fracture
  - closed -- no break in skin
  - open fracture -- skin broken
  - comminuted -- broken ends of bones are fragmented

Fractures

- Common types of fracture
  - Pott’s -- distal fracture of fibula and/or tibia
  - Colles’s -- distal fracture of radius and/or ulna
  - stress fracture -- microscopic fissures from repeated strenuous activities

Repair of a Fracture

- Formation of fracture hematoma
  - damaged blood vessels produce clot in 6-8 hours, bone cells die
  - inflammation brings in phagocytic cells for clean-up duty
  - new capillaries grow into damaged area

- Formation of fibrocartilagenous (soft) callus
  - fibroblasts invade & lay down collagen fibers
  - chondroblasts produce fibrocartilage to span the broken ends of the bone

Repair of a Fracture

- Formation of bony (hard) callus
  - osteoblasts secrete spongy bone that joins 2 broken ends of bone
  - lasts 3-4 months

- Bone remodeling
  - compact bone replaces the spongy bone in the bony callus
  - surface is remodeled back to normal shape
Calcium Homeostasis & Bone Tissue

- Skeleton is a reservoir of calcium & phosphate
- Calcium ions involved with many body systems
  - nerve & muscle cell function
  - blood clotting
  - enzyme function in many biochemical reactions
- Small changes in blood levels of Ca\(^{2+}\) can be deadly
  - plasma level maintained 9-11 mg/100mL
  - cardiac arrest if too high
  - respiratory arrest if too low

Hormonal Influences

- Parathyroid hormone (PTH) is secreted if Ca\(^{2+}\) levels fall
  - osteoclast activity increased, kidney retains Ca\(^{2+}\) and produces calcitriol
- Calcitonin hormone is secreted from parafollicular cells in thyroid if Ca\(^{2+}\) blood levels get too high
  - inhibits osteoclast activity
  - increases bone formation by osteoblasts

Exercise and Bone Tissue

- Bone has the ability to alter its strength in response to mechanical stress by increasing deposition of mineral salts and production of collagen fibers
  - Removal of mechanical stress leads to weakening of bone through demineralization and collagen reduction
    - reduced activity while in a cast
    - astronauts in weightless environment
    - bedridden person
  - Weight-bearing activities, such as walking or weightlifting, help build and retain bone mass

Aging and Bone Tissue

- Of two principal effects of aging on bone, the first is the loss of calcium and other minerals from bone matrix, which may result in osteoporosis.
  - very rapid in women 40-45 as estrogens levels decrease
  - in males, begins after age 60
- The second principal effect of aging on the skeletal system is a decreased rate of protein synthesis
  - decrease in collagen production which gives bone its tensile strength
  - decrease in growth hormone
  - bone becomes brittle & susceptible to fracture
Osteoporosis

- Decreased bone mass resulting in porous bones

- Those at risk
  - white, thin, menopausal, smoking, drinking, female with family history
  - athletes who are not menstruating due to decreased body fat & decreased estrogen levels
  - people allergic to milk or with eating disorders whose intake of calcium is too low

- Prevention or decrease in severity
  - adequate diet, weight-bearing exercise, & estrogen replacement therapy (for menopausal women)
  - behavior when young may be most important factor

Disorders of Bone Ossification

- Rickets
  - calcium salts are not deposited properly
  - bones of growing children are soft
  - bowed legs, skull, rib cage, and pelvic deformities result

- Osteomalacia
  - “adult rickets”
  - new adult bone produced during remodeling fails to ossify
  - hip fractures are common

- Caused by vitamin D deficiency