Skeletal System: Osseous Tissue
(Chapter 6)

Lecture Materials
for
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Primary Sources for figures and content:


Skeletal system components: 
bones, cartilage, ligaments, other CT that stabilize the bones

Functions:
1. Support: framework & structure of body
2. Storage of minerals and lipids
   Minerals: calcium and phosphate (for osmotic regulation, enzyme function, nerve impulses)
   Yellow marrow = triglycerides
3. Blood cell production (all formed elements)
   red marrow: stem cells → hematopoiesis
4. Protection: surround soft tissues
5. Leverage for movement (levers upon which skeletal muscles act)

Bone Classification:
206 major bones
1. Axial skeleton: protection & support
   skull, vertebrae, ribs
2. Appendicular skeleton: locomotion & manipulation, limbs and limb girdles
All bones can be classified by shape:

1. Long bones: longer than wide, consist of shaft and 2 ends, e.g. bones of appendages
2. Short bones: approximately equal in all dimensions, e.g. carpals, tarsals
3. Flat bones: thin, 2 parallel surfaces, e.g. skull, sternum, ribs, scapula
4. Irregular bones: complex shapes, e.g. vertebrae, os coxa
5. Sesamoid bones: seed shaped, form in tendon, e.g. patella, total number can vary
6. Sutural bones: extra bones in sutures of skull
Bone Structure
-a bone is an organ consisting of many tissue types: osseous, nervous, cartilage, fibrous CT, blood, etc.
-all bones consist of 2 types of bone tissue
1. Compact bone: solid, dense bone, makes up surfaces and shafts
2. Spongy bone/ Cancellous bone: meshy, makes up interior of bones, houses red marrow in spaces
-bones are not flat on surface: have projections, depressions, and holes for muscle attachment, blood & nerve supply
Long bone structure (handout)

1. diaphysis = hollow shaft of compact bone
2. medullary (marrow) cavity = center of diaphysis, contains yellow marrow (triglycerides for energy reserve)

3. epiphysis = expanded end of bone, surface of compact bone, center filled with spongy bone with red marrow in spaces (produces blood cells)
4. epiphyseal line or plate = cartilage that marks connection of diaphysis with epiphysis
   - line- adults, narrow, a.k.a. metaphysis plate - thick, allows growth during childhood

5. periosteum = 2 layer covering around outside of bone:
   - outer fibrous layer
   - inner cellular layer
6. endosteum = cellular layer, covers all inside surfaces
7. articular cartilage = hyaline cartilage on end where bone contacts another, no periosteum or perichondrium

Joint / Articulation = connection between two bones, surrounded by CT capsule, lined with synovial membrane
Joint cavity filled with synovial fluid to reduce friction on articular cartilage
Flat bone structure
-thin layer of spongy bone with red marrow between two layers of compact bone
-covered by periosteum and endosteum
-site of most hematopoiesis

Bone Histology
bone = osseous tissue, supporting CT
-consists of specialized cells in a matrix of fibers and ground substance
Characteristics of bone
1. dense matrix packed with calcium salts
2. osteocytes in lacunae
3. canaliculi for exchange of nutrients & waste
4. two layer periosteum, covers bone except at articular surfaces

Matrix - 98% of bone tissue
1/3 = osteoid; organic part: collagen fibers + ground substance, tough & flexible
2/3 = densely packed crystals of hydroxyapatite (calcium salts, mostly calcium phosphate), hard but brittle

Cells - only 2% of bone (handout)
1. Osteocytes = mature bone cells
   - no cell division
   - located in lacunae between layers of matrix called lamellae
   - canaliculi link lacunae to each other and blood supply
osteocytes linked to each other via gap junctions on cell projections in canaliculi: allow exchange of nutrients and wastes

osteocytes function to maintain protein and mineral content of matrix

can also participate in bone repair: become active when broken free of lacuna

2. Osteoblasts

perform osteogenesis =

produce osteoid (organic components of matrix)

promote deposit of calcium salts which spontaneously form hydroxyapatite

once enclosed in lacuna by matrix, osteoblast differentiates into osteocyte and no longer produces new matrix

bone fracture frees osteocytes which revert to osteoblasts to produce matrix again
3. Osteoprogenitor cells (mesenchymal cells)
   - bone stem cell that produces daughters that become osteoblasts for repair and growth
   - located in endosteum and inner periosteum

4. Osteoclasts
   - large, multinuclear
   - derived from monocytes (macrophages)
   - perform osteolysis =
     - digest and dissolve bone matrix, release minerals for use in blood, or recycling during bone remodeling
Structure of compact bone (handout)
- consists of osteons: parallel to surface
- each osteon around central canal: contains blood vessels and nerves
- perforating canals perpendicular to osteons connecting osteons
- osteon built of layers of matrix secreted by osteoblasts
- each layer = concentric lamella
- osteocytes located in lacunae between lamellae
- osteocytes connected to neighboring cells and central canal via canaliculi
- interstitial lamellae fill spaces between osteons
-circumferential lamellae run perimeter inside and out in contact with endosteum and periosteum
-compact bone designed to receive stress from one direction
-very strong parallel to osteons
-weak perpendicular to osteons

**Structure of spongy bone**

- lamellae = meshwork called trabeculae (no osteons)
- red marrow fills spaces around trabeculae
- osteocytes in lacunae linked by canaliculi
- no direct blood supply (no central canals)
-nutrients diffuse into canaliculi in trabeculae from red marrow
-spongy bone makes up low stress bones, or areas of bone where stress comes from multiple directions
-provides light weight strength
Periosteum
1. Fibrous outer layer: dense irregular CT
2. Cellular inner layer: osteoprogenitor cells

Functions:
1. Isolate bone from surrounding tissues
2. Site for attachment (tendons, ligaments, joint capsules)
3. Route for nerves and blood vessels to enter bone
4. Participates in bone growth and repair
**Endosteum**
- thin cellular layer
- lines medullary cavity, central canals, and covers trabeculae
- consists of osteoprogenitor cells
- cells become active during bone growth and repair
Bone Growth
- begins 6-8 weeks post fertilization
- continues through puberty (18-25 y)

Osteogenesis = ossification =
formation of bone

NOT calcification = hardening of matrix or cytoplasm with calcium, can happen to many tissues

Two types of ossification:
1. Intramembranous: forms flat bones
2. Endochondrial: forms long bones
Intramembranous Ossification

Bone develops from mesenchyme or fibrous CT in deep layers of dermis, e.g. skull bones, mandible, clavicals (go to handout)

1. An ossification center appears in the fibrous connective tissue membrane.
   - Selected centrally located mesenchymal cells cluster and differentiate into osteoblasts, forming an ossification center.

2. Bone matrix (osteoid) is secreted within the fibrous membrane.
   - Osteoblasts begin to secrete osteoid, which is mineralized within a few days.
   - Trapped osteoblasts become osteocytes.

3. Woven bone and periositeum form.
   - Accumulating osteoid is laid down between embryonic blood vessels, which form a random network. The result is a network (instead of lamellae) of trabeculae.
   - Vascularized mesenchyme condenses on the external face of the woven bone and becomes the periosteum.

4. Bone collar of compact bone forms and red marrow appears.
   - Trabeculae just deep to the periosteum thicken, forming a woven bone collar that is later replaced with mature lamellar bone.
   - Spongy bone (diploë), consisting of distinct trabeculae, persists internally and its vascular tissue becomes red marrow.
Endochondrial Ossification

Bone develops from hyaline cartilage models. The cartilage grows by interstitial and appositional growth and is slowly replaced by bone from the inside out (go to handout).
Bone Remodeling
- bones not static: constantly recycled/renewed
- 5-7% of skeleton recycled / week
- osteoclasts secrete:
  1. Lysosomal enzymes: digest osteoid
  2. Hydrochloric acid: solubilize calcium salts
- osteoblasts secrete:
  1. Osteoid (organic matrix)
  2. Alkaline phosphatase: induces mineralization of osteoid (complete mineralization takes ~1 week)

Bones adapt:
- stressed bones growth thicker
- bumps and ridges for muscle attachment enlarge when muscles used heavily
- bones weaken with inactivity: up to 1/3 of mass lost with few weeks inactivity
- heavy metals can get incorporated
*condition of bones depends on interplay between osteoclast and osteoblast activity
Skeleton as a calcium reserve
- calcium important to normal function of neurons and muscle
- blood calcium: 9-11mg/100ml
- if blood levels to high: nerve and muscle cells non responsive
- if blood levels too low: nerve and muscle cells hyper-excitabile → convulsions, death

Calcium homeostasis depends on:
1. Storage in the bones
2. Absorption in the GI
3. Excretion at the kidneys

These factors controlled by hormones to regulate blood calcium levels
If blood calcium levels low:
Parathyroid hormone (from parathyroid gland) triggers:
1. Increase osteoclast activity (↓ storage)
2. Enhanced calcitriol action (↑ absorption)
3. Decreased calcium excretion at kidney
If blood calcium levels high:
Calcitonin (from thyroid gland) triggers:
1. Inhibition of osteoclast activity (↑ storage)
2. Increased calcium excretion at kidney

Nutritional and Hormone Effects on Bone
-many nutrients and hormones required for normal bone growth and maintenance:
1. **Calcium and phosphate** salts: from food, for mineralization of matrix
2. **Calcitriol**: from kidney, for absorption of calcium and phosphate
3. **Vitamin C**: from food, for collagen synthesis and osteoblast differentiation
4. **Vitamin A**: from carotene in food, for normal bone growth in children
5. **Vitamins K and B12**: from food, for synthesis of osteoid proteins
6. **Growth Hormone**: from pituitary gland, for protein synthesis and cell growth
7. **Thyroxin**: from thyroid gland, for cell metabolism and osteoblast activity
8. **Estrogens and Androgens**: from gonads, for epiphyseal closure
9. **Calcitonin**: from thyroid gland AND
10. **Parathyroid Hormone**: from parathyroid gland, to regulate calcium and phosphate levels in body fluids; affects bone composition
Abnormalities

Genetic/Physiological abnormalities:
1. Giantism: too much Growth Hormone prior to epiphyseal closure, bones grow excessively large
2. Acromegaly: too much GH after closure, bones don’t grow but all cartilage does (ribs, nose, ears, articular cartilage)
3. Pituitary dwarfism: not enough GH, bones fail to elongate

Diet related abnormalities:
1. Scurvy: lack Vit.C, low collagen content, reduced bone mass, bones brittle
2. Osteomalacia: lack Vit.D → lack calcitriol, osteoid produced but not mineralized, bones flexible.
   Called Rickets in children and leads to permanent deformity
Fractures
-bones break in response to excessive stress
-bones designed to heal

(Step 1): Immediately after the fracture, extensive bleeding occurs. Over a period of several hours, a large blood clot, or fracture hematoma, develops.

(Step 2): An internal callus forms as a network of spongy bone unites the inner surfaces, and an external callus of cartilage and bone stabilizes the outer edges.

(Step 3): The cartilage of the external callus has been replaced by bone, and struts of spongy bone now unite the broken ends. Fragments of dead bone and the areas of bone closest to the break have been removed and replaced.

(Step 4): A swelling initially marks the location of the fracture. Over time, this region will be remodeled, and little evidence of the fracture will remain.
Effects of Aging

Osteopenia = reduction in bone mass
- all adults suffer some degree
- osteoclasts out-work osteoblasts (sex hormones in youth inhibit osteoclasts)
- women: 8%/decade after 40
- men: 3%/decade after 40

Osteoporosis = reduction in bone mass that compromises function

More common in women:
- thinner bones to start
- greater rate of osteopenia