CARTILAGE, BONE & JOINTS

CARTILAGE

The Basics:
- specialized connective tissue
- rigid, elastic & resilient – RESISTS COMPRESSION
- AVASCULAR – necessary nutrients diffuse through matrix

The Components:
- perichondrium – dense regularly arranged connective tissue (type I collagen); ensheaths cartilage; houses vasculature; home of chondroblast precursors (look like fibroblasts)
- chondroblast – progenitor of chondrocyte; secretes type II collagen and other extracellular matrix components (chondroblasts build); lines the border b/t perichondrium and matrix
- chondrocyte – mature cartilage cell surrounded by matrix; reside in spaces called lacunae
- matrix – composed of fibers (either collagenous or elastic) and ground substance (rich in glycosaminoglycans [GAGs], especially chondroitin sulfates); provides rigidity, elasticity, and resilience

Methods of Growth:
- appositional – increasing in GIRTH or WIDTH; chondroblasts deposit collagen/matrix on surface of pre-existing cartilage
- interstitial – increasing LENGTH; specific for endochondral bone formation; chondrocytes divide and secrete matrix from within their lacunae*

* NOTE: Cartilage cells divide in all types of cartilage; not only associated with endochondral bone formation.

Types of Cartilage:
1) hyaline
2) elastic
3) fibrous
<table>
<thead>
<tr>
<th></th>
<th>HYALINE</th>
<th>ELASTIC</th>
<th>FIBROUS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>APPEARANCE</strong></td>
<td>Hundreds of eyes staring back at you.</td>
<td></td>
<td>Layers of collagen fibers visible.</td>
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<tr>
<td><strong>FUNCTION</strong></td>
<td>Support of tissues &amp; organs; bone development</td>
<td>Support with flexibility</td>
<td>Support with great tensile strength (must sustain pressure &amp; shear)</td>
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<tr>
<td><strong>LOCATIONS</strong></td>
<td>Nasal septum, larynx, tracheal rings, articular surfaces of joints, sternal margins of ribs</td>
<td>External ear, external auditory canal, epiglottis, part of laryngeal cartilage, Eustachian tubes</td>
<td>Intervertebral discs, pubic symphisis, articular disks of sternoclavicular joint</td>
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<td><strong>MATRIX</strong></td>
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<tr>
<td><strong>COLLAGEN</strong></td>
<td>Type II (thin fibrils)</td>
<td>Type II w/ elastic fibers</td>
<td>Type I collagen layers interrupt matrix (oriented parallel to stress plane)</td>
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<tr>
<td><strong>GROUND SUBSTANCE</strong></td>
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<tr>
<td></td>
<td>3 types of GAGS</td>
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<tr>
<td></td>
<td>• chondroitin sulfate</td>
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<td></td>
<td>• keratin sulfate</td>
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<td></td>
<td>• hyaluronic acid (proteoglycan monomer = GAG + core protein)</td>
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<td></td>
<td>contains a lot of water</td>
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<tr>
<td><strong>STAINING</strong></td>
<td>Matrix – basophilic due to GAGs (neg. charged sulfate grps)</td>
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<tr>
<td></td>
<td>Territorial matrix – surrounds lacunae; more basophilic due to high concentration of proteoglycans secreted by chondrocytes</td>
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<tr>
<td></td>
<td>Chondrocytes – active in matrix production; dark blue nuclei; clear areas b/c Golgi apparatus and lipid droplets</td>
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<td>Weigert stain – elastic fibers stain black</td>
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<tr>
<td></td>
<td>H&amp;E – type I collagen layers are intense pink; matrix is basophilic</td>
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<td></td>
<td>Orcein van Giesen Elastic stain – Fibrocartilage is reddish brown (nucleus pulposus at center); NOTE: hyaline cartilage is yellow</td>
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</tbody>
</table>
BONE

The Basics:
• specialized connective tissue made up of cells and mineralized matrix
• functions in support & protection; acts as storage site of calcium & phosphate;
  encloses hematopoietic elements of bone marrow

The Components:
• cells:
  o osteoblasts – secrete collagen & ground substance that constitutes
    unmineralized bone (osteoid). Subsequently initiates calcification of matrix.
    ▪ cuboidal or polygonal in shape
    ▪ aggregation as single layer on surfaces of forming bone
    ▪ basophilic due to abundant rER for production of collagen and
      proteoglycans
    ▪ eccentric & euchromatic nuclei, prominent nucleolus large Golgi
    ▪ newly secreted osteoid stains lightly because it’s not calcified & appears
      as light band between osteoblast & bone
  o osteoclasts – functions in bone resorption and remodeling. Rests on surface of
    bone in shallow pits called Howship’s lacunae. Release lysosomal enzymes
    like collagenase to digest bone. Activity increased by parathyroid hormone
    and decreased by calcitonin
    ▪ large & multinucleated (from monocyte lineage)
    ▪ acidophilic cytoplasm due to lysosomal enzymes
    ▪ on EM can see ruffled border – plasma membrane infoldings that directly
      contact bone; creates sealed off space for release of lysosomal contents
      & secretion of acid onto bone
  o osteocytes – mature and non-dividing – the differentiated osteoblast. Enclosed
    in bone matrix. Maintain bone matrix via limited synthesis and resorption –
    important for maintaining blood Ca++ levels
    ▪ enclosed in lacunae
    ▪ less cytoplasmic basophilia than osteoblasts
    ▪ in ground sections, canaliculi connecting osteocytes are evident
• matrix: type I collagen; ground substance w/ proteoglycans & non-collagenous
  glycoproteins (ALL MINERALIZED)
• mineral: calcium phosphate in form of hydroxyapatite crystals

Types of Bone:
• mature vs. immature:
  o mature – adult bone
    ▪ compact – arranged in Haversian systems; found as dense layer on outside
      of bones
    ▪ spongy – trabecular appearance; found in interior of bone
  o immature (a.k.a. woven) – bone tissue initially deposited in skeleton in fetal
    life or following fracture
nonlamellar (woven), irregularly arranged collagenous fibers in proteoglycan matrix
- more cells and more ground substance than mature bone
- stains more intensely w/ hematoxylin because it’s not mineralized

- long vs. flat:
  - long – bones like tibia & metacarpals; growth by endochondral ossification
    - diaphysis – shaft consisting of marrow cavity surrounded by compact bone (little spongy bone b/t compact bone & marrow)
    - epiphysis – expanded end; mainly spongy bone surrounded by thin outer shell of compact bone
    - metaphysis – flared portion b/t diaphysis & epiphysis
    - epiphyseal plate – cartilage that separates epiphyseal & diaphyseal cavities which maintains growth process
  - flat – thin and plate-like; bones of skull & sternum; growth by intramembranous ossification

Methods of Growth:
- appositional vs. interstitial
  - ALL GROWTH OF BONE TISSUE IS APPOSITIONAL
  - long bones grow in WIDTH via appositional growth (on pre-existing surface) of bone tissue beneath periosteum
  - long bones grown in LENGTH due to interstitial growth (formation of new cartilage within existing cartilage mass) of cartilage model

- endochondral vs. intramembranous
  - These describe mechanism of growth only – not type of existing bone. The remodeling process replaces the initial bone laid down by these processes.
  - endochondral – CARTILAGE MODEL SERVES AS PRECURSOR
    - fetal development
      - mesenchymal cells condense, aggregate, and differentiate into chondroblasts
      - chondroblasts lay down cartilage model; cartilage model grows in length by interstitial growth and width by appositional growth
      - bony collar develops around shaft of growing bone
      - calcification of cartilage matrix occurs in this region causing death of chondrocytes
      - lacunae become confluent, creating larger cavity in center of model
      - periosteal cells migrate in; differentiate into osteoblasts, and begin to lay down osteoid on calcified spicules that remain in cavity
      - calcified cartilage that remains is basophilic. New bone is eosinophilic.
    - growth in young adulthood.
      - epiphyseal cartilage serves as the site of continued bone growth
      - from epiphysis to diaphysis, the zones of growth are:
        - zone of reserve cartilage – randomly arranged chondrocytes; no proliferation
- **zone of proliferation** – chondrocytes undergo division and are organized in distinct columns (stacks of poker chips)
- **zone of hypertrophy** – chondrocytes and lacunae are enlarged
- **zone of calcification** – matrix begins to mineralize, causing chondrocyte death
- **zone of ossification** – osteoblasts deposit osteoid on exposed cartilage
- **zone of resorption** – nearest diaphysis; osteoclasts absorb oldest bone on spicules

- **intramembranous** – NO CARTILAGE MODEL
  - Mesenchymal cells begin to condense, area becomes vascularized.
  - Mesenchymal cells become larger, rounder. Cytoplasm changes from eosinophilic to basophilic as cells differentiate into osteoblasts.
  - Osteoblasts secrete collagen and proteoglycans of matrix (osteoid). When surrounded by matrix, these osteoblasts become osteocytes and maintain bone.
  - Matrix is calcified and forms shape of spicules, which enlarge and interconnect, forming trabeculae
  - Osteoblasts on surface of spicules reproduce to maintain population capable of growth.
  - Fibrous periosteum surrounds growing bone.
  - As bone continues to grow, it undergoes remodeling via resorption by osteoclasts.

**Preparation of Samples for Microscopy: Ground bone vs. Decalcified bone:**

- **Ground bone**
  - Dried and finely ground preparations of bone that are not decalcified
    - Black and tan
    - Allows visualization of **Haversian systems** (a.k.a. osteons)
      - Structural unit of compact bone
      - Consists of **Haversian canals** which carry blood vessels, nerves, lymphatics
      - Surrounded by concentric lamellae of bone. The outermost rings are oldest
      - Within lamellae are lacunae containing osteocytes. Lacunae and osteocytes are connected via thread-like canaliculi that contain the cytoplasmic processes of osteocytes. Allow gap junction communication between osteocytes, circulation of extracellular fluid, wastes and metabolites.
      - Volkmann’s canals run perpendicular to Haversian canals, passing through the lamellae. They carry neurovascular bundles from endosteum and periosteum into Haversian canals.
      - Interstitial lamellae are remnants of Haversian systems that have been resorbed. Lie between osteons.
      - Cementing lines delimit Haversian systems. Basophilic due to proteoglycans.
• **Decalcified bone**
  - Demineralized with acid and then stained with H&E
  - Able to see cells, organic matrix & periosteum
    - **Periosteum** – sheath of dense connective tissue surrounding outer surface of bone containing osteoprogenitor cells
    - **Endosteum** – lines bone cavities (marrow cavity of compact bone & the marrow spaces between trabeculae of spongy bone). Contains endosteal cells which can differentiate into osteoblasts

### Bone vs. Cartilage

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<thead>
<tr>
<th></th>
<th>Bone</th>
<th>Cartilage</th>
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<tbody>
<tr>
<td><strong>H&amp;E Staining Properties</strong></td>
<td>Eosinophilic</td>
<td>Basophilic</td>
</tr>
<tr>
<td><strong>Function</strong></td>
<td>Rigid structure &amp; support</td>
<td>Shape, precursor to bone</td>
</tr>
<tr>
<td><strong>Nutrients</strong></td>
<td>HC, VC, &amp; canaliculi</td>
<td>Diffusion across matrix</td>
</tr>
<tr>
<td><strong>Growth</strong></td>
<td>Appositional</td>
<td>Appositional &amp; interstitial</td>
</tr>
<tr>
<td><strong>Cells</strong></td>
<td>Osteocytes, -blasts, -clasts</td>
<td>Chondrocytes</td>
</tr>
<tr>
<td><strong>Matrix</strong></td>
<td>Mineralized; type I collagen</td>
<td>GAGs, type II collagen (hyaline &amp; elastic) and type I collagen (fibrocartilage)</td>
</tr>
</tbody>
</table>

### Joints

**Types of Joints:**
- immovable or slightly movable
  - **syndesmoses** – *fibrous* joints; bone connected to connective tissue
  - **synchondroses** – *cartilaginous* joints; bone connected to cartilage
  - **synostoses** – *osseous* joints; bone connected to bone
- freely movable joints
  - articulating bones separated by a fluid-filled cavity
  - **synovial**
  - **diarthroid**

**Terms:**
- **synovial cavity** – fluid-filled space between two bones
- **synovial fluid** – comprised of water and GAGs; maintains articular cartilage (provides nutrients than enter cartilage through diffusion)
- **synovial membrane** – specialized secretory connective tissue; consists of collagenous fibers and fibroblasts; fibroblasts secrete synovial fluid; highly vascular; may be attached to perichondrium at lateral regions of articular cartilage
- **synovial villi** – folds of the synovial membrane; project into the synovial cavity to allow increased secretion/absorption of synovial fluid