BONES AND SKELETAL TISSUE

Introduction

-skeleton contains cartilage and bones

-the emphasis on this section is the structure and function of bone tissue and on the dynamics of its formation and remodeling throughout life.

I. Skeletal Cartilage

-the fetal skeleton is made of cartilage and fibrous membranes, which are eventually replaced by bones.

-cartilage not replaced by bones is found in regions where more resilient skeletal tissue is needed; skeletal cartilages can be hyaline, elastic and fibrocartilage.

A. HYALINE CARTILAGE

-provides support with flexibility and resilience.

-it is the most abundant type of skeletal cartilage.

-locations:

-ends of movable joints - articular cartilage.

-connecting the ribs to the sternum - costal cartilage.

-forming the skeleton of the larynx - laryngeal cartilage.

-reinforcing passageways to the respiratory system - tracheal and bronchial cartilages.

-supporting the external nose - nasal cartilages.

B. ELASTIC CARTILAGE

-able to withstand repeated bending.

-found in two skeletal locations: external ear and the epiglottis.

C. FIBROCARTILAGE

-highly compressible and provides for tensile strength.

-found in skeletal locations that are subjected to heavy pressure and stretch.

-pad-like cartilages of the knee - menisci.

-intervertebral disks.

D. GROWTH OF CARTILAGE

1. Appositional growth: growth from the outside.

-chondrocytes below surrounding perichondrium secrete a new matrix against the existing cartilage.

2. Interstitial growth: growth from within.

-lacunae bound chondrocyte divide and secrete new matrix.

II. Functions of Bones:

A. Support: provide the framework of the body and cradle organs.

B. Protection: provided by the skull, ribs, and the vertebral column.

C. Movement: muscles attach to the bones and use them as levers to move body parts.

D. Mineral storage: bone is a reservoir for minerals (calcium and phosphate).

E. Blood cell formation: (hematopoiesis) occurs within certain bone marrow cavities.

III. Classification of bones

-classified by shape as long, short, flat, or irregular.
-contain varying proportions of two basic types of osseous tissue:
-compact bone: smooth and homogenous.
-spongy bone: composed of trabeculae and has much open space; space between the trabeculae is filled with marrow.

A. LONG BONES (elongated size, not overall size)

-longer than wide
-include most bones of limbs.
-primarily compact bone but can contain spongy bone in the interior

B. SHORT BONES

-include bones of the wrist and ankle.
-roughly cube-like.
-mostly spongy bone with a thin compact bone surface layer.

C. FLAT BONES

-include the sternum, ribs, and most skull bones.
-thin, flattened, and slightly curved.
-two, roughly parallel, compact bone surfaces with enclosing a layer of spongy bone.

D. IRREGULAR BONES (complicated shape).

-include the vertebrae and hip bones.
-don't fit in any of the previous classes.
-mostly spongy bone enclosed by a thin layer of compact bone.

IV. Bone Structure

-bones are organs because they contain different kinds of tissue (osseous tissue predominates; nervous tissue, muscle and epithelium also present.

A. GROSS ANATOMY OF BONE

1. Structure of long bones.

a. Diaphysis: shaft; composed of compact bone surrounding the medullary cavity (contains yellow marrow)

b. Epiphyses: found on bone ends and are more expanded than the diaphysis: compact bone on exterior, spongy bone interior; articular cartilage covers joint surfaces.

c. Epiphyseal Line: found between the diaphysis and the epiphyses, remnant of epiphyseal plate.

d. Membranes: CT linings of the internal and external surfaces bone surfaces.

-periosteum: doubled layered membrane that lines the external bone surface.

-outer fibrous layer - dense irregular connective tissue.

-inner osteogenic layer - abuts bone surfaces; osteoblasts, osteoclasts.

-periosteum is richly supplied with nerves and blood vessels, secured to the underlying bone by collagen fibers extending from the outer fibrous layer (Sharpey's Fibers).

-endosteum: a delicate connective tissue membrane lining all internal bone surfaces: trabeculae of spongy bones in marrow cavities, medullary cavities in compact bone, canals of compact bone; contains osteoblasts and osteoclasts.

2. Structure of short, irregular and flat bones:

-thin plates of periosteum covered compact bone enclosing endosteum covered spongy bone - no diaphysis or epiphyses.

-bone marrow is found between the trabeculae.

-in flat bone the inner layer is spongy bone = diploë.

3. Location of hematopoietic tissue in bones: (red marrow).

-found within some cavities of spongy bone in long bones and in diploë of flat bones.

-newborns: medullary cavities/all areas of spongy bone contain red marrow.

-adults: medullary cavities contain yellow marrow; little red marrow present in spongy bone, exceptions are femur and humerus. Hematopoiesis is mostly in red marrow of dipolë of flat bones (sternum), in some irregular bones (hip bone) and in the head of the femur and humerus.

B. MICROSCOPIC STRUCTURE OF BONES

1. Compact Bone:
   -very dense, contains thorough system of canals and passageways.
   -osteon (Haversian System) - structural unit of compact bone.
   a. General structure.
      -elongated cylinders running parallel to the long axis of the bone.
      -formed groups of hallow tubes of bone matrix arranged concentrically.
      -each matrix tube is called a lamella.
      -collagen fibers within lamella run in a single direction, in adjacent lamella fibers run in opposite directions - withstand tensions.
      -core of the osteon - Haversian canal (central canal) - contains blood vessels and nerve fibers serving cells in osteon.
      -Perforating canals (Volkmann's): lie perpendicular to the long axis of bone.
      -connect nerve and vascular supply of periosteum to those in the central canals and medullary .
   b. Detailed structure.
      -osteocyte: spider shaped mature bone cells occupy lacunae between lamellae.
      -hair-like canals (canaliculi) connect lacunae to each other and to the central canal, effectively connect all osteocytes in the osteon, allow osteocytes to be well nourished.
      -interstitial lamellae: incomplete lamellae.
      -circumferential lamellae: lamellae beneath periosteum, extend around circumference of the shaft.

2. Spongy bone:
   -consists of trabeculae a few cell layers thick; contain irregular lamellae and osteocytes interconnected with canaliculi; no osteons.
   -trabeculae are arranged along the lines of stress.

C. CHEMICAL STRUCTURE (COMPOSITION) OF BONE:

1. Organic components:
   -cells: osteoblasts, osteocytes, osteoclasts.
   -osteoid: organic part of matrix, secreted by osteoblast: GAG, glycoproteins, and collagen fibers; responsible for bone's flexibility and high tensile strength.

2. Inorganic components: (65% by mass)

-hydroxyapatites: - mineral salts, mostly calcium phosphates.
- present as crystals between collagen fibers in the osteoid.
- responsible for hardness of bones.

V. Bone Development:

-osteogenesis (ossification): the process of bone formation.
-in embryos - leads to the formation of bony skeleton.
-in childhood through early adulthood - results in bone growth and increased size.
-in adulthood - remodeling and repair of bones.

A. FORMATION OF BONY SKELETON: (ossification in embryo).

-at 6 weeks, the skeleton of an embryo - fibrous membranes/hyaline cartilage.
-bone formation involves replacing this skeleton with bone tissue.
-intramembranous ossification: bone develops from a fibrous membrane.
-endochondral ossification: bone develops from hyaline cartilage.

1. Intramembranous ossification: formation of all flat bones.

-mesenchymal cells of fibrous membrane differentiate into osteoblasts, secrete osteoid.
-osteoid become mineralized, osteoblasts trapped in lacunae become osteocytes.
-as the osteoid deposits accumulate and mineralization continues, a network of trabeculae form that encloses local blood vessels - woven bone.
-collagen fibers are arranged irregularly.
-collagen fibers form networks, not lamellae.
-concurrently, a layer of vascular mesenchyme condenses external to the woven bone, periosteum development.
-trabeculae below periosteum thicken, form continuous plates of bone, first woven bone later compact bone.
-trabeculae in center of the bone remain distinct so spongy bone is produced.
-vascular tissue within spongy bone differentiates into red marrow, diploë.

2. Endochondral ossification: forms other bones of the skeleton (non-flat bones).

-template is hyaline cartilage.
-begins at the primary ossification center at the center of the hyaline cartilage shaft.
-perichondrium is infiltrated with blood vessels, becomes a vascularized periosteum.
-osteoblasts of newly "converted" periosteum secretes osteoid against hyaline cartilage shaft, encases it in a bone collar.

-hyaline cartilage in center shaft calcifies, bone collar continues formation externally.
-chondrocytes within the shaft enlarge, surrounding cartilage calcifies, nutrients cannot get to center of the shaft, chondrocytes die, the matrix begins to deteriorate - cavity formation.
-forming cavities are invaded by periosteal bud - brings a nutrient artery, vein, lymphatics, nerve fiber, red bone marrow elements, osteoblast/osteoclasts into the cavity.
-entering osteoblasts secrete osteoid around remaining cartilage fragments - bone covered cartilage trabeculae (precursor of spongy bone).
-primary ossification centers enlarge proximally and distally - osteoclasts break down newly formed spongy bone, open up a medullary cavity in the center of the shaft, final step in shaft ossification.
-recall that throughout the fetal period, rapidly growing epiphyses consists only of cartilage.
-shortly before birth, secondary ossification centers appear at the epiphyses.
-cartilage at the center of the secondary ossification centers in the epiphyses calcifies and deteriorates to form a cavity.
-entry of the periosteal bud.
-bone matrix secreted around the remaining cartilage fragments.
-spongy bone is retained and there is no cavity formation.
-cartilage remains only at articular cartilage and at epiphyseal plates.

B. BONE GROWTH

-ossification in childhood and early adulthood results in bone growth and increased size.
-long bones lengthen by interstitial growth of epiphyseal plates.
-all bones grow in thickness by appositional growth.

1. Growth in length of bones:

-longitudinal bone growth mimics events of endochondral ossification.
-is a function of hyaline cartilage in epiphyseal plates and articular surfaces.
-cells in this layer of cartilage are arranged in tall columns.
-cells at the top of the column are actively dividing, chondroblasts (zone 1) - the epiphysis is pushed away from diaphysis and the entire bone lengthens.
-older chondrocytes closer to the shaft enlarge, matrix is calcified (zone 2).
-chondrocytes die, matrix deteriorates (zone 3).

-ossification begins - spongy bone is formed and later resorbed by osteoclasts, the medullary cavity lengthens as bone lengthens (zone 4).

2. Appositional Growth:
-bone must widen as they lengthen.
-osteoclasts below periosteum produce the bone matrix - compact bone (osteons).
-this is accompanied by bone resorption on endosteal surface.

VI. Bone Homeostasis:

A. BONE REMODELING
-in adult bone deposit and bone resorption is occurring continuously.
-in healthy adult total bone mass stays constant.
-rate of bone deposit = the rate of bone resorption.

1. Bone Deposit:
-occurs where bone was injured or added bone strength is required; by osteoblasts.
-site of bone deposit is an unmineralized band of bone matrix called the osteoid seam.
-between the osteoid seam and the old mineralized bone there is abrupt transition, the calcification front; osteoid must mature before becoming calcified.
-controls of calcification:
-product of local concentration of calcium and phosphate ions.
-matrix proteins (osteocnectin and osteocalcin).
-rich supply of alkaline phosphatase - found in the membrane of osteoblast.

2. Bone Resorption:
-conducted by osteoclasts.
-osteoclasts secrete lysosomal enzymes that digest organic matrix, and metabolic acids that solubilize calcium salts.

B. CONTROL OF REMODELING

1. Hormonal control:
-involves interaction of parathyroid hormone (PTH) and calcitonin.
-hormonal controls act to maintain blood calcium ion homeostasis rather than the strength of the skeleton.

2. Mechanical factors:
-bone remodeling occurs in response to mechanical stress and gravity.

-Woff's Law: bone growth/remodeling occurs in response to forces/stresses.
-unlike hormonal regulation, control by mechanical forces serves the need of the skeleton itself, keeping bones strong where stresses are acting.
-therefore, hormonal factors determine whether and when remodeling will occur in response to blood calcium levels, while mechanical and gravitational forces determine where remodeling will occur.

C. REPAIR OF FRACTURES

-bones are susceptible to breaks -trauma, weakness.
-fractures are treated by reduction: realignment of broken ends.
-closed reduction by hand and open reduction by surgery.
- repair process:
-hematoma formation: blood vessels in the bone and surrounding torn tissue hemorrhage forming a clot and local swelling.
-fibrocartilage callus formation: formation of soft granulation tissue.
-capillaries grow into hematoma, phagocytic cells clean up debris.
-fibroblasts and osteoblast migrate to the fracture site from nearby periosteal and endosteal membranes to begin reconstruction of bone.
-calcification of fibrocartilaginous callus.
-remodeling: excess material is removed and compact bone is laid down to reconstruct the shaft.

VII. Homeostatic Imbalances

A. OSTEOPOROSIS: - bone resorption is greater than bone deposit.

-total bone mass reduced, chemical composition of the matrix stays the same.
-bones become more porous and brittle.
-spongy bone is most vulnerable (neck, femur, spine).
-occurs mostly in women: estrogens mediate PTH activity.
-other factors: poor diet, too little exercise.
-treatment: supplemental calcium, vitamin D, increased exercise.

B. OSTEOMALACIA: "soft bones".

-bones are inadequately mineralized.
-osteoid produced, however no calcium deposition.
-bones become severely bent and deformed.
-caused by vitamin D deficiency.

C. RICKETS:

-similar to osteomalacia but in children.
-this is more severe since bones are still growing.
-caused by vitamin D deficiency.

D. PAGET'S DISEASE:

-excessive and abnormal bone formation and resorption.
-high ratio of woven bone to compact bone.
-bones are generally weak.