Ch. 6 – The skeleton

Skeletal Cartilage

Contains no blood vessels or nerves

Surrounded by the perichondrium (dense irregular connective tissue) that resists outward expansion

Three types (you know this already) – hyaline, elastic, and fibrocartilage

Hyaline Cartilage - Provides support, flexibility, and resilience

Most abundant skeletal cartilage

Is present in these cartilages:

- *Articular* – covers the ends of long bones
- *Costal* – connects the ribs to the sternum
- *Respiratory* – makes up the larynx and reinforces air passages
- *Nasal* – supports the nose
- Embryonic/fetal skeleton

Elastic Cartilage - Similar to hyaline cartilage but contains more elastic fibers

Found in the external ear and the epiglottis

Fibrocartilage - Highly compressed; great tensile strength; contains more collagen fibers

Found in menisci of the knee, in intervertebral discs, and pubic symphysis

Growth of Cartilage

Appositional – growth from the outside in; cells in the perichondrium secrete matrix against the external face of existing cartilage.

Interstitial – lacunae-bound chondrocytes inside the cartilage divide and secrete new matrix, expanding the cartilage from within

Calcification of cartilage occurs

- During normal bone growth
- During old age

Classification of Bones

Axial skeleton – bones of the skull, vertebral column, and rib cage

Appendicular skeleton – bones of the upper and lower limbs, shoulder, and hip

Long bones – longer than they are wide (ex: humerus)

Short bones – wider than they are long (ex:

- Cube-shaped bones of the wrist and ankle
- Bones that form within tendons (ex: patella)

Flat bones – thin, flattened, and curved (ex: sternum, most skull bones)

Irregular bones – bones with complicated shapes (ex: vertebrae, hip bones)

Functions of Bones

Support

Protection

Movement Leverage

Mineral storage – (calcium, phosphorus, etc)

Blood cell formation – hematopoiesis in marrow

Bone Markings

Bulges, depressions, and holes which serve as:

- Sites of attachment for muscles, ligaments, and tendons
- Joint surfaces
- Conduits for blood vessels and nerves
- Identifying markings

Projections – Sites of Muscle and Ligament Attachment

Tuberosity – rounded projection
Crest – narrow, prominent ridge of bone
Trochanter – large, blunt, irregular surface
Line – narrow ridge of bone
Tubercle – small rounded projection
Epicondyle – raised area above a condyle
Spine – sharp, slender projection
Process – any bony prominence

Projections That Help to Form Joints

Head – bony expansion carried on a narrow neck
Facet – smooth, nearly flat articular surface
Condyle – rounded articular projection
Ramus – armlike bar of bone

Depressions and Openings

Meatus – canal-like passageway
Sinus – cavity within a bone
Fossa – shallow, basinlike depression
Groove – furrow
Fissure – narrow, slitlike opening
Foramen – round or oval opening through a bone

Gross Anatomy of Bones: Bone Textures

Compact bone – dense outer layer
Spongy bone – honeycomb of trabeculae filled with yellow bone marrow

Structure of Long Bone

Long bones consist of a *diaphysis* and an *epiphysis*

Diaphysis

- Tubular shaft that forms the axis of long bones
- Composed of compact bone
- Surrounds the *medullary cavity,* which contains *y*ellow bone marrow (fat)

Epiphyses

- Expanded ends of long bones
- Exterior is compact bone, interior is spongy bone
- Joint surface is covered with articular cartilage (hyaline)
- *Epiphyseal line* separates the diaphysis from the epiphyses

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Bone Membranes

Periosteum – double-layered protective membrane

Outer *fibrous layer* is dense regular connective tissue

Inner *osteogenic layer* is composed of *osteoblasts* and *osteoclasts*

Richly supplied with nerve fibers, blood, and lymphatic vessels, which enter the bone via nutrient *foramina*

Secured to underlying bone by "Sharpey's fibers"

Endosteum – delicate membrane covering internal surfaces of bone

Structure of Short, Irregular, and Flat Bones

Thin plates of periosteum-covered compact bone on the outside with endosteum-covered spongy bone (*diploë*) on the inside

Have no diaphysis or epiphyses

Contain bone marrow between the trabeculae, but no marrow cavity

Location of Hematopoietic Tissue (Red Marrow)

In infants – in medullary cavity and all areas of spongy bone

In adults - in diploë of flat bones, and the head of the femur and humerus

Microscopic Structure of Bone: Compact Bone

Haversian systems, or *osteons* – the structural unit of compact bone

Lamella – weight-bearing, column-like matrix tubes; made of collagen

Haversian/*central* canal – central channel; contains blood vessels and nerves

Volkmann's canals – channels lying at right angles to the central canal; connect blood and nerve supply of periosteum to that of the Haversian canal

Osteocytes – mature bone cells

Lacunae – small cavities in bone that contain osteocytes

Canaliculi – hairlike canals that connect lacunae to each other and the central canal

Microscopic Structure of Bone: Spongy Bone

Appears poorly organized compared to compact bone

Trabeculae align precisely along the lines of stress and help the bone resist stress

No osteons present

Organic Chemical Composition of Bone

Osteoblasts – bone-forming cells

Osteocytes – mature bone cells

Osteoclasts – large cells that resorb or break down bone matrix

Osteoid – organic, unmineralized part of nonliving bone matrix; includes ground substance (proteoglycans, glycoproteins) and collagen fibers

Inorganic Chemical Composition of Bone

Hydroxyapatites, or mineral salts

Sixty-five percent of bone by mass

Mainly calcium phosphates

Gives bone <u>hardness</u> and resistance to <u>compression</u>, <u>tension</u>

Calcium phosphate forms tightly packed crystals in and around the collagen fibers

Bone Development

Osteogenesis and *ossification* – processes of bone tissue formation; lead to:

Formation of bony skeleton in embryos
Bone growth until early adulthood
Bone thickness, remodeling, and repair

Formation of the Bony Skeleton

Begins at week 8 of embryo development
Intramembranous ossification – bone develops from a fibrous membrane
Endochondral ossification – bone forms by replacing hyaline cartilage

Intramembranous Ossification

Forms most of the flat bones of the skull and the clavicles
Fibrous connective tissue membranes formed by mesenchymal cells

Stages of Intramembranous Ossification

Ossification center appears in the fibrous connective tissue membrane
Bone matrix is secreted within the fibrous membrane
Woven bone and periosteum form
Bone collar of compact bone forms, and red marrow appears

Endochondral Ossification

Begins in second month of development
Uses hyaline cartilage "bones" as models for bone construction
Requires breakdown of hyaline cartilage prior to ossification

Stages of Endochondral Ossification

Formation of bone collar around the diaphysis of the hyaline cartilage model
Cavitation of the hyaline cartilage - Calcification kills the chondrocytes, then matrix begins to deteriorate
Invasion of internal cavities by the periosteal bud and spongy bone formation
Formation of the medullary cavity as the diaphysis elongates; appearance of secondary ossification centers in the epiphyses
Ossification of the epiphyses, with hyaline cartilage remaining only in the epiphyseal plates

Postnatal Bone Growth - Growth in length of long bones

-Cartilage on the side of the epiphyseal plate closest to the epiphysis is relatively inactive
-Cartilage abutting the shaft of the bone organizes into a pattern that allows fast, efficient growth
-Cells of the epiphyseal plate proximal to the resting cartilage form three functionally different zones: growth, transformation, and osteogenic

Functional Zones in Long Bone Growth

Growth zone – cartilage cells undergo mitosis, pushing the epiphysis away from the diaphysis
Transformation zone – older cells enlarge, the matrix becomes calcified, cartilage cells die, and the matrix begins to deteriorate
Osteogenic zone – new bone formation occurs

Long Bone Growth and Remodeling

Growth in length – cartilage continually grows and is replaced by bone
Growth in width - bone is resorbed and added to by appositional growth

Hormonal Regulation of Bone Growth During Youth

Infancy and childhood - epiphyseal plate activity is stimulated by growth hormone
During puberty, testosterone and estrogens:
- Initially promote adolescent growth spurts
- Cause masculinization and feminization of specific parts of the skeleton
- Later induce epiphyseal plate closure, ending longitudinal bone growth

Bone Remodeling

Remodeling units – adjacent osteoblasts and osteoclasts deposit and resorb bone at periosteal and endosteal surfaces

Bone Deposition

Occurs where bone is injured or added where strength is needed
Requires a diet rich in protein, vitamins C, D, and A, calcium, phosphorus, magnesium, and manganese; alkaline phosphatase essential for mineralization

Sites of new matrix deposition are revealed by the:
- *Osteoid seam* – unmineralized band of bone matrix
- *Calcification front* – abrupt transition zone between the osteoid seam and the older mineralized bone

Bone Resorption - accomplished by osteoclasts

Resorption bays – grooves formed by osteoclasts as they break down bone matrix
Resorption involves osteoclast secretion of:
- Lysosomal enzymes that digest organic matrix
- Acids that convert calcium salts into soluble forms

Dissolved matrix is transcytosed across the osteoclast's cell where it is secreted into the interstitial fluid and then into the blood

Importance of Ionic Calcium in the Body

Calcium is necessary for:
- Transmission of nerve impulses
- Muscle contraction
- Blood coagulation
- Secretion by glands and nerve cells
- Cell division

Control of Remodeling

Two control loops regulate bone remodeling
- Hormonal mechanism maintains calcium homeostasis in the blood
- Mechanical and gravitational forces acting on the skeleton

Hormonal Mechanism

Rising blood Ca^{2+} levels trigger the thyroid to release calcitonin

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Calcitonin stimulates calcium salt deposit in bone

Falling blood Ca^{2+} levels signal the parathyroid glands to release PTH

PTH signals osteoclasts to degrade bone matrix and release Ca^{2+} into the blood

Response to Mechanical Stress

Wolff's law – a bone grows or remodels in response to the forces or demands placed upon it

Observations supporting Wolff's law include

- Long bones are thickest midway along the shaft (where bending stress is greatest)
- Curved bones are thickest where they are most likely to buckle

Response to Mechanical Stress

Trabeculae form along lines of stress

Large, bony projections occur where heavy, active muscles attach

Bone Fractures (Breaks)

Bone fractures are classified by:

- The position of the bone ends after fracture
- The completeness of the break
- The orientation of the bone to the long axis
- Whether or not the bones ends penetrate the skin

Types of Bone Fractures

Nondisplaced – bone ends retain their normal position

Displaced – bone ends are out of normal alignment

Complete – bone is broken all the way through

Incomplete – bone is not broken all the way through

Linear – the fracture is parallel to the long axis of the bone

Transverse – the fracture is perpendicular to the long axis of the bone

Compound (open) – bone ends penetrate the skin

Simple (closed) – bone ends do not penetrate the skin

Comminuted – bone fragments into three or more pieces; common in the elderly

Spiral – ragged break when bone is excessively twisted; common sports injury

Depressed – broken bone portion pressed inward; typical skull fracture

Compression – bone is crushed; common in porous bones

Epiphyseal – epiphysis separates from diaphysis along epiphyseal line; occurs where cartilage cells are dying

Greenstick – incomplete fracture where one side of the bone breaks and the other side bends; common in children

Stages in the Healing of a Bone Fracture

Hematoma formation

- Torn blood vessels hemorrhage
- A mass of clotted blood (hematoma) forms at the fracture site
- Site becomes swollen, painful, and inflamed

Fibrocartilaginous callus forms

Granulation tissue (soft callus) forms a few days after the fracture

Capillaries grow into the tissue and phagocytic cells begin cleaning debris

The fibrocartilaginous callus forms when:

- Osteoblasts and fibroblasts migrate to the fracture and begin reconstructing the bone
- Fibroblasts secrete collagen fibers that connect broken bone ends
- Osteoblasts begin forming spongy bone
- Osteoblasts furthest from capillaries secrete an externally bulging cartilaginous matrix that later calcifies

Bony callus formation

- New bone trabeculae appear in the fibrocartilaginous callus
- Fibrocartilaginous callus converts into a bony (hard) callus
- Bone callus begins 3-4 weeks after injury, and continues until firm union is formed 2-3 months later

Bone remodeling

- Excess material on the bone shaft exterior and in medullary canal is removed
- Compact bone is laid down to reconstruct shaft walls

Homeostatic Imbalances

Osteomalacia

- Bones are inadequately mineralized causing softened, weakened bones
- Main symptom is pain when weight is put on the affected bone
- Caused by insufficient calcium in the diet, or by vitamin D deficiency

Rickets

- Bones of children are inadequately mineralized = softened, weakened bones
- Bowed legs and deformities of the pelvis, skull, and rib cage are common
- Caused by insufficient Ca in the diet or by vitamin D deficiency

Osteoporosis

- Group of diseases in which bone reabsorption outpaces bone deposit
- Spongy bone of the spine is most vulnerable
- Occurs most often in postmenopausal women
- Bones become so fragile that sneezing or stepping off a curb causes fractures

Osteoporosis: Treatment

Calcium and vitamin D supplements

Increased weight-bearing exercise

Hormone (estrogen) replacement therapy (HRT) slows bone loss

Natural progesterone cream prompts new bone growth

Statins increase bone mineral density

Developmental Aspects of Bones

Mesoderm → mesenchyme→ membranes & cartilages → embryonic skeleton

The embryonic skeleton ossifies in a predictable timetable that allows fetal age to be easily determined from sonograms.

At birth, most long bones are well ossified (except for their epiphyses)

By age 25, nearly all bones are completely ossified

In old age, bone resorption predominates

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