

INTRODUCTION

System Concept

1. Component organs

- a. Bones
- b. Joints (articulations)

2. Tissues represented in organs

- a. Osseous (bone) -- most abundant
- b. Cartilage
 - _ Second in abundance
 - _ Hyaline, elastic & fibrous
- c. Miscellaneous connective
 - _ Dense collagenous -- e.g. perichondrium, ligaments
 - _ Dense elastic -- e.g. stylohyoid ligament
 - _ Reticular -- bone marrow
 - _ Adipose -- bone marrow
- d. Nervous
- e. Vascular (blood vessels)

3. Notochord

- _ Early embryonic -- 18 days - 3 months
- _ Original skeleton -- support in long axis
- _ Dense fibrous connective tissue rod
- _ Mostly disappears -- remnants between some vertebrae

Functions

1. Support & maintain body form -- most common
2. Protection -- e.g. cranium
3. Leverage for movement
 - a. Anchorage for muscles
 - b. Joints
 - _ Pivot points
 - _ Limit direction of movement
 - _ Limit degree of movement
4. Hemopoiesis -- blood cell formation
5. Storage
 - a. Nutrients
 - _ Minerals -- e.g. Ca, Fe
 - _ Organic -- fat
 - b. Toxic metals -- e.g. Pb, Cd, Hg

Skeleton As A Whole

1. Axial
 - a. Meaning -- upright axis
 - b. Components -- 80 bones
 - _ Skull -- 28
 - _ Hyoid -- 1
 - _ Vertebral Column -- 26
 - _ Thorax -- 25

c. Wormian (sutural) bones

- _ In addition to 80
- _ Variable number, size & shape
- _ Randomly formed as cranial sutures develop
- _ Possibly genetically determined

2. Appendicular

a. Meaning -- appendages

b. Components -- 126 bones

- _ Pectoral girdle -- 4
- _ Upper extremity -- 60
- _ Pelvic girdle -- 2
- _ Lower extremity -- 60

c. Sesamoid bones

- _ In addition to 126 -- excluding patellae
- _ Variable number, size & shape (ovoid)
- _ Appear at any time -- fetal through old age
- _ In tendons of higher stress joints
 - e.g. thumbs & great toes
 - e.g. gastrocnemius
- _ Function(s) disputed
 - modify muscle force or pull ?
 - reduce friction ?

d. Non-sesamoid accessory bones

- _ Mostly in feet
- _ From formation (ossification) irregularities

BONE STRUCTURE

Descriptive Terms

1. Shape Classification [*not very useful*]

a. Long

- _ Linear, elongated
- _ Hollow diaphysis -- epiphyses only at ends
- _ Extremity bones -- except wrist & ankle

b. Short

- _ Compact, squared off
- _ Inner spongy, outer shell compact
- _ Carpals & tarsals

c. Flat

- _ Cranial bones best example
- _ Sternum

d. Irregular -- all those not as above

2. Projections & processes

- a. Process (epiphysis) -- generic for any projection
- b. Condyle or head-- smooth, for articulation
- c. Spine or spinous process -- sharp or ridge-like
- d. Trochanter or tubercle -- rough, for muscle attachment

3. Depressions & openings

- a. Foramen, canal or meatus -- hole
- b. Fossa -- depression
- c. Notch -- gap or break in contour

Bone Marrow

1. Red marrow

a. Locations

_ Within spaces

-- of spongy bone

-- marrow (medullary) cavities

_ Immature (fetus-young child) -- 100 % in all bones

_ Mature -- great decrease in amount

-- cranial (not other skull bones)

-- axial (vertebral bodies, ribs, sternum)

-- clavicles, scapulae, os coxae

-- humerus & femur (only proximal epiphyses)

b. Functions

- _ Hemopoiesis
 - Erythropoiesis (RBC)
 - Leukopoiesis (4 of 5 WBC's)
 - Thrombopoiesis (platelet)
- _ Phagocytosis
 - old erythrocytes
 - immune-related
- _ Storage -- Fe

c. Structure

- _ Reticular tissue framework
- _ Myeloid (stem or CFU) cells
 - altered mesenchyme cell
 - hemopoietic, becoming RBC, WBC or platelet
- _ Immature blood cell stages
- _ Plasma cells -- from lymph nodes (e.g.)
- _ Adipocytes -- scattered groups
- _ Vascular
 - blood vessels (abundant)
 - sinusoids (pouch-like)

2. Yellow marrow

a. Locations

- _ Immature -- none
- _ Mature -- begins at puberty
 - more abundant than red
 - all bony spaces not containing red

b. Origin & structure

- _ Conversion from red marrow
- _ Myeloid cells diminish in number
- _ Adipocytes increase in number

c. Function

- _ Fat storage
- _ Red marrow functions disappear

d. Reversion

- _ Can go back to red marrow
- _ If needed -- loss of red marrow (e.g.)
- _ Adipocytes diminish
- _ Myeloid cells reproduce

3. Intergrades

- _ Red & yellow categories not always clearly defined
- _ Some marrow may have half adipose/half myeloid (e.g.)
- _ Many possible ratios of red/yellow mix
- _ Sometimes represents conversion or reversion in progress

SKELETAL PART	MALE	FEMALE
General Size	Larger	Smaller
General Density	Matrix more dense	Matrix less dense
General Shape	Contours sharper/pronounced	Contours more rounded
General Process	More prominent/massive	Less prominent/massive
Mandible	Relatively larger	Relatively smaller
Pelvic Depth	Deeper	More shallow
Pelvic Width	Funnel shaped	Flaring
True Pelvis	Heart shaped	Wide oval
Pubic Arch	$\leq 90^\circ$	$> 90^\circ$
Sacrum	Wider, curved, horizontal	Narrow, straight, vertical
Coccyx	More rigid	More flexible

AGE CHANGES

Infancy To Adulthood

1. Timing

- _ Women -- approx. 18 years
- _ Men -- approx. 25 years

2. General

- a. Size increase -- absolute, not relative
- b. Size variations -- relative [*details below*]
- c. Osseous tissue increases

3. Head

a. Size/shape

- _ Becomes smaller proportionate to trunk -- began larger
- _ Face quite reduced
 - lack of teeth diminishes jaws
 - nose not yet projecting
- _ Elongated -- similar to very developed brain's shape

b. Cranial size increases -- 350 cc - 1500 cc

c. Fontanel

- _ Soft spots between cranial bones
- _ Unossified tissue -- membrane bones [*details later*]
- _ Gradually disappear as bones meet -- 1.5 - 2 years

d. Sutures

- _ Follow fontanel disappearance
- _ Final fusion 20⁺ years

4. Thorax

- _ Shape from more rounded to elliptical
- _ Due to rib & sternal development

5. Legs

- _ Become longer proportionate to trunk
- _ Began shorter

6. Vertebral column

- a. Thoracic curvature -- present at birth
- b. Sacral curvature -- present at birth
- c. Cervical curvature
 - _ Appears after birth
 - _ From head raising
- d. Lumbar curvature
 - _ Appears after birth
 - _ From walking

7. Epiphyses

- a. Epiphyseal plates (disks)
 - _ Hyaline cartilage -- middle of epiphysis
 - _ Growth zone -- permits lengthening
- b. Gradual replacement by osseous tissue
 - _ Earlier -- same rate as cartilage increase
 - _ Later -- ossification faster

c. Metaphyses

- _ Complete closure (ossification) of plates
- _ 18 years (women) -- reason for shorter avg. height
- _ 25 years (men)
- _ Exception -- clavicles 30⁺ years

After Maturity

1. General

- a. Surfaces more textured
- b. Contours (margins) become shaggy & enhanced
- c. Ridges & processes more prominent

2. Osseous tissue

- a. General -- decreased amount, density & integrity
- b. Inorganic component -- minerals
 - _ Women -- more pronounced
 - _ Osteoporosis -- pathological, not normal

3. Kyphosis

- _ Increased thoracic curvature
- _ Stoop-shouldered condition

4. Sesamoid bones

- _ Increase in number
- _ Mostly in great toes & Achilles tendon

5. Sternum

- _ Manubrium & gladiolus fuse
- _ Xiphoid ossifies -- eventually fuses with gladiolus

6. Clavicles -- epiphyseal closure

CARTILAGE

General

1. Temporary

- _ Most hyaline will not persist through life
- _ Gradually replaced by osseous tissue
- _ Nearly entire skeleton hyaline in early fetus
- _ Reason
 - _ Cartilage develops rapidly compared with osseous
 - _ Temporary support provided while skeleton matures

2. Permanent

- a. All elastic
- b. All fibrous
- c. Some hyaline
 - _ Articular cartilages
 - _ Costal
 - _ Nasal
 - _ Respiratory -- laryngeal, tracheal, bronchial

Development and Growth

1. Mesenchyme

- a. Description
 - _ Mass of mesenchymal cells
 - _ Suspended in non-(or delicate) fibered matrix
- b. Activity

- _ Extra division -- cells now predominate
- _ Most cells differentiate into chondroblasts
- _ Outside cells become fibroblasts [*details later*]
- _ Cells under fibroblasts remain mesenchymal

2. Chondroblasts

a. Mitotic division produces more chondroblasts

b. Matrix deposition

1) Secrete unique cartilaginous matrix

2) Semi-solid -- compressible & flexible

3) Fibers

-- hyaline has delicate collagenous

-- fibrous has thick, close collagenous

-- elastic has thick, close elastic

4) Ground substance

-- glycosaminoglycans: - hyaluronic acid
 - chondroitin sulfates
 - keratan sulfate

-- proteoglycans - above + proteins

-- create semi-solid gel

-- provide scaffolding for fibers

-- bind tissue fluid for diffusion

c. Cells now farther apart & entrapped in lacunae

3. Growth patterns/regions

a. Interstitial

_ Deep within cartilage

_ Chondroblasts divide

- _ New matrix formed -- pushes cells apart
- _ Causes inward expansion of cartilage

b. Appositional

- _ Beneath perichondrium
- _ New chondroblasts form matrix
- _ Causes outward expansion of cartilage

4. Chondrocytes

- _ Name for former chondroblast when matrix completed
- _ Basically a maintenance cell

5. Perichondrium

a. Outermost mesenchymal cells

- _ Differentiate into fibroblasts
- _ Secrete ground substance & form collagenous fibers
- _ Become fibrocytes

b. Inner zone

- _ Between perichondrium and cartilage proper
- _ Mesenchymal cells remain
- _ Differentiate into chondroblasts as needed
 - for appositional growth
 - for repair

Mature Changes

1. Repair & regeneration

a. Mildly damaged cartilage

- _ Inner zone mesenchymal cells migrate to site
- _ Differentiate into chondroblasts

- _ Damage well repaired

b. Severely damaged cartilage

- _ Chondroblasts appear at site
- _ Little or no new cartilage appears
- _ Dense fibrous connective tissue usually develops
- _ Could later become ossified

2. Degeneration (regression)

a. Purpose

- _ Temporary strengthening
- _ Usually prior to replacement with osseous tissue

b. Occurrence

- _ Normal part of osseous tissue formation
- _ Abnormal in permanent cartilage
 - sometimes occurs in old age
 - may occur as mistake in regeneration

c. Process

- _ Chondrocytes enlarge (hypertrophy)
- _ Secrete alkaline phosphatase
- _ Mineralization of matrix -- minerals precipitated
- _ Diffusion not possible through solid matrix
- _ Chondrocytes die -- phagocytes clear out debris

OSSEOUS TISSUE

General

1. Comparisons with cartilage

- a. Matrix mineralization normal -- does not cause cell death
- b. Cells (osteocytes) also trapped within lacunae
- c. Cellular nourishment enabled in solid matrix -- canaliculi
- d. Highly vascular
- e. Developmental steps essentially the same
- f. Appositional growth only

2. Matrix composition

a. Organic

1) Functions

- maintains shape
- provides some flexibility
- fiber surfaces substrate for minerals

2) Components

- primarily collagenous fibers (>90%)
- proteoglycans

b. Inorganic

1) Function -- hardness

2) Components -- mineral salt crystals

- mostly hydroxyapatite - $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$
- needle-like; parallel collagenous fibers
- others - e.g. CO_3 , Mg, Cl, F, Na, Fe, citrate

Ossification (Osteogenesis)

1. Mesenchyme

- _ Basically same as cartilage
- _ Mesenchymal cells become osteoblasts

2. Osteoblasts

- a. Basically same as cartilage
- b. Intercellular connections
 - _ Extensions from cells
 - _ Meet each other
 - _ Those near blood vessels extend there as well
- c. Mineralization of matrix
 - _ Following ground substance & collagenous fibers
 - _ Extracellular enzymes secreted
 - _ Mineral salts from blood (abundant supply)
 - _ Precipitation of mineral salts [*details above*]
 - _ Matrix now true solid

3. Cellular nourishment

- _ Matrix does not quite touch osteoblast membranes
- _ Intercellular extensions
 - _ Disconnect from each other
 - _ Withdraw almost to bodies of cells in lacunae
- _ Spaces become filled with tissue fluid
- _ Canaliculi
 - _ Tiny canals -- formerly occupied by extensions
 - _ All lacunae & vascular channels interconnected

4. Growth pattern/regions

- _ Appositional only
- _ No interstitial -- solid matrix cannot expand from within

5. Osteocytes

- _ Name for former osteoblast when matrix completed
- _ Maintenance cell

6. Periosteum

- _ Basically same as perichondrium of cartilage
- _ Inner zone of mesenchymal cells present just as in cartilage

Mature Changes

1. Age changes

a. Immature bone

- _ Called woven (-fibered) or spicular
- _ Initial form produced by ossification process
- _ Principal type before birth
- _ Randomly arranged matrix parts & osteocytes
- _ Spongy in texture -- vascular spaces, not marrow
- _ Can be produced faster than mature type

b. Mature bone

- 1) Called lamellar or parallel-fibered
- 2) Most appears after birth
- 3) Woven bone first destroyed
 - osteoclasts secrete catalytic enzymes
 - osseous matrix broken down
 - osteocytes die

-- osteoclasts phagocytize debris

- 4) Lamellar bone produced by new ossification
- 5) Lamellae are merely repeating layers of matrix
- 6) Present in both compact & spongy arrangements

2. Remodeling

a. Process

- _ Destruction of lamellar bone
- _ Osteoclasts [*previously described*]
- _ New ossification replaces old -- still lamellar

b. Timing

- _ Occurs in scattered areas -- systematic
- _ Always occurring
- _ Continues throughout life
- _ Average life of osteocyte -- 25 years
- _ Slows in later years

c. Benefits

- 1) Adjust strength -- varies with degree of stresses
- 2) Shape changes
 - accommodate new stress patterns
 - contours, processes modified as needed
- 3) Fresh minerals -- enhances body calcium balance
- 4) New organic matrix -- weakens & becomes brittle

3. Repair & regeneration

a. Osseous tissue usually regenerates completely

b. Failure to regenerate

- _ If peri-/endosteum destroyed

 - inner zone mesenchymal cells required

- _ If vascular supply destroyed

c. Role of blood vessels

- _ Essential to supply minerals for inorganic matrix

- _ Stimulate mesenchymal cells to become osteoblasts

- _ Where blood vessels have yet to be regenerated:

 - chondroblasts appear

 - hyaline cartilage develops

 - blood vessels later lead to degeneration

 - ossification now occurs

Intramembranous Ossification

1. Concept

- _ Direct ossification

- _ No cartilaginous precursor -- [*explained later*]

2. Occurrence

a. Mostly flat skull bones -- whole bone or only a part

b. Completely membrane bones

- _ Parietals

- _ Frontal

- _ Lacrimals

- _ Nasals

- _ Maxillae
- _ Zygomatics
- _ Sesamoids

c. Partly membrane, remainder cartilage replacement [*below*]

- _ Occipital
- _ Temporals
- _ Sphenoid
- _ Mandible

3. Process

a. Occurs within special membrane

- _ Vascular, dense collagenous tissue
- _ Contains mesenchymal cells

b. Ossification center

- _ One or more, depending on bone -- e.g. occipital 2
- _ Osteoblasts develop
- _ Typical ossification process occurs

c. Fontanel -- [*discussed previously*]

- _ Unossified membrane
- _ Permit skull distortion during birth

Intracartilaginous Ossification

1. Concept

a. Indirect ossification

b. Cartilage development initially

- _ Hyaline
- _ Miniature of future bone

c. Systematically replaced

- _ Invasion by blood vessels
- _ Degeneration of cartilage
- _ Ossification occurs
 - on framework of debris
 - in appositional layers

d. Timing

- _ Most begin about 8 weeks in fetus
- _ Some not until childhood -- e.g. carpals & tarsals

e. Resulting osseous tissue same as intramembranous

2. Occurrence

- a. Non-membranous skull bones
- b. Non-membranous portions of mixed skull bones
- c. Remainder of axial skeleton
- d. Appendicular skeleton -- except sesamoids

3. Process [*long bone as example*]

a. Primary ossification center

- 1) Within central diaphysis
- 2) Spongy bone initially
- 3) Expands towards epiphyses
- 4) Later degenerates -- marrow cavity develops

b. Periosteal bone

- 1) Occurs around primary center
- 2) Beneath developing periosteum
- 3) Successive layers added appositionally
- 4) Permits growth in diameter of bone

- innermost layers degenerate
- new outer layers added
- wall maintains same thickness

c. Secondary ossification centers

- 1) Most begin during childhood up through adolescence
- 2) One within each epiphysis
- 3) Same basic process as primary center
- 4) Spongy bone will remain
- 5) Will continue towards diaphyseal ossification center

d. Growth in length

- 1) Primary & secondary centers do not meet yet
- 2) Cartilage remains between them -- epiphyseal plate
- 3) Cartilage of plate proliferates interstitially
- 4) Replaced at the same rate by ossification
- 5) Continued proliferation & replacement
- 6) Eventually proliferation slows, then stops
- 7) Ossification now complete -- epiphyses closed

4. Variations

- _ Different bones have varying numbers of ossification centers
- _ Short bones only have one center
- _ Irregular bones vary greatly -- e.g. :
 - _ Typical vertebra -- 3 primary/5 secondary
 - _ Hyoid -- 6 centers (no primary/secondary)
 - _ Scapula -- 8 centers