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 – red bone marrow

-- Adipose – yellow 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	≤ 90˚	> 90˚
Sacrum	Narrow, straight, vertical	Wider, curved, horizontal
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. Fontanels

-- 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 - $Ca_{10}(PO_4)_6(OH)_2$

-- 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 osseous tissue

-- 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 osseous tissue

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 tissue 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 tissue

-- 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. Fontanels -- [*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. Comparison with intramembranous

a. Intramembranous and intracartilaginous <u>not</u> different “kinds”, but the same tissue formed in two different situations (environments)

b. Spongy and compact not two “kinds”, but only density and arrangement of components vary.

c. Woven and lamellar are closest to being two “kinds” of tissue.

4. 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

5. 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