Bone Formation, Growth, and Remodeling
Pre-natal Ossification

Embryonic skeleton:

• fashioned from fibrous membranes or cartilage to accommodate mitosis.

• 2 types of pre-natal ossification (bone formation)

1. Intramembranous
   • Bone develops from fibrous membrane
   • Forms bones of skull and clavicle (most flat bones)
   • Contributes to the growth of short bones and thickening of long bones
   • Begins at 8 weeks of development

2. Endochondral
   • Bone develops from hyaline cartilage
   • Responsible for the formation of short and long bones
   • Begins 2nd month of development
Intramembranous Ossification
(prenatal)
Intramembranous Ossification
(prenatal)
Intramembranous Ossification
(prenatal)

Mesenchymal cells create fibrous CT framework for ossification

Some mesenchymal cells differentiate into osteoblasts in an ossification center

Osteoblasts secrete bone matrix, osteoid
Intramembranous Ossification (prenatal)

Mineralization and calcification of osteoid

Trapped osteoblasts become osteocytes
Intramembranous Ossification (prenatal)

Several points of ossification occur and fuse forming spongy bone around embryonic blood vessels.

Mesenchyme on bone face condense and differentiate into periosteum.
Intramembranous Ossification (prenatal)

The woven bone at the outer edge is remodeled and replaced by **compact bone**

Spongy bone (diploë) remains

cavities made up of trabeculae fill with **red marrow** created from vessels (vascular tissue)

Note: Osteoblasts remain on bone surface to grow/remodel when needed
An anatomical feature of the infant human skull comprising any of the soft membranous gaps (sutures) between the cranial bones of an infant.

Fontanelles:
1. allow room for the baby’s brain to grow
2. enable the head to be compressed during delivery.
Endochondral Ossification

1. Development of cartilage model
Endochondral Ossification

**Bone collar** formed around diaphysis by osteoblasts located on inner side of perichondrium

The collar impedes diffusion of oxygen and nutrients and the underlying cartilage, promoting degenerative changes there
**Endochondral Ossification**

Cartilage calcifies, then the cells die and cavities form (cavitates).

Death of chondrocytes creates a porous structure consisting of calcified cartilage remnants which become covered by a layer of osteoblast.

Bone collar provides stability during cavitation.

Cartilage elsewhere continues to elongate.
Endochondral Ossification

Blood vessels from perichondrium (now the periosteum) penetrate through the bone collar, bringing osteoprogenitor cells to the porous central region.

Periosteal bud (lymph, blood vessels, nerves, red marrow, osteoblasts and osteoclasts) enters cavity and builds spongy bone.
Endochondral Ossification

Secondary Ossification Center forms in epiphysis

Osteoclasts dissolve spongy bone to create medullary cavity
Endochondral Ossification

Hyaline only remains on epiphyseal surface (articular cartilage) and at diaphysis and epiphysis junction, to form the epiphyseal plates.
Growing taller throughout childhood!

**Endochondral Ossification:**
the process by which most bones in the body grow
Growing Taller!
(A closer look at the epiphyseal plate)

Lots of activity!
Growing Taller!
(A closer look at the epiphyseal plate)

- typical hyaline cartilage (resting)
  1- Resting zone

- rapidly mitotic cartilage, lengthening bone; chondrocytes form columns
  2- Growth zone

- enlarging size of chondrocytes (hypertrophy), this hypertrophy compresses the matrix into thin septa between chondrocytes
  3- Hypertrophy zone

- matrix of cartilage calcifies and cells die forming small cavities
  4- Calcification zone

- Osteoblasts adhere to the remnants of calcified cartilage matrix and produce woven bone. Later this bone reshapes into spongy bone converted into medullary cavity or compact bone later as bone grows.
  5- Ossification zone
Longitudinal Bone Growth

- Longitudinal Growth (interstitial) – cartilage continually grows and is replaced by bone
  - Bones lengthen entirely by growth of the **epiphyseal plates**
  - Cartilage is replaced with bone as quickly as it grows
  - *Epiphyseal plate maintains constant thickness*

![Diagram of longitudinal bone growth and remodeling process](image)
Bone collar
When does lengthening stop?

- End of adolescence - lengthening stops
  - Chondrocytes stop mitosis.
  - Plate thins out and replaced by bone
  - Diaphysis and epiphysis fuse to be one bone
    - Epiphyseal plate closure (18 yr old females, 21 yr old males)
- Thickening of bone continuous throughout life
Appositional Bone Growth

- Growing bones widen as they lengthen
- Appositional growth – growth of a bone by addition of bone tissue to its surface
- Bone is resorbed at endosteal surface and added at periosteal surface
  - Osteoblasts – add bone tissue to the external surface of the diaphysis
  - Osteoclasts – remove bone from the internal surface of the diaphysis
http://depts.washington.edu/bonebio/ASBMRed/growth/newlongbone2.swf

http://depts.washington.edu/bonebio/ASBMRed/growth/newBMUbu.swf

http://highered.mheducation.com/sites/dl/free/0072495855/291136/BoneGrowth.swf

Recommended
http://www.johnwiley.net.au/highered/interactions/media/Support/content/Support/skel2a/frameset.htm

http://www.doitpoms.ac.uk/tlplib/bones/flash/EndochondralOssification.swf
Bone Remodeling

- **Reshaping of the skeleton during growth**
- **Maintain calcium levels**
- **Repair of microfractures caused by everyday stresses**

Involves:
- Dissolving/destroying bone
- New bone growth
Dissolved material passed through osteoclasts and into bloodstream for reuse by the body (endocytosis and transcytosis).
Bone Remodeling

• Bone Deposition
  – Occurs when bone is injured or extra strength is needed
  – Requires a healthy diet - protein, vitamins C, D, and A, and minerals (calcium, phosphorus, magnesium, manganese, etc.)

• Bone Resorption
  – Accomplished by **Osteoclasts** (multinucleate phagocytic cells)
  – Resorption involves osteoclast secretion of:
    • Lysosomal enzymes that digest organic matrix
    • HCl that converts calcium salts into soluble forms
  – Dissolved matrix is endocytosed and transcytosed into the interstitial fluid → the blood
Bone is Dynamic!
Bone is constantly remodeling and recycling

- Coupled process between:
  - Bone deposition (by osteoblasts)
  - Bone destruction/resorption (by osteoclasts)
- 5-7% of bone mass recycled weekly
- All spongy bone replaced every 3-4 years.
- All compact bone replaced every 10 years.

Prevents mineral salts from crystallizing; protecting against brittle bones and fractures
Bone growth regulated by hormones

- **Human Growth Hormone (HGH):** from pituitary gland in brain promotes epiphyseal plate activity
- **Thyroid hormones:** regulate HGH for proper bone proportions
- **Puberty:** Testosterone or Estrogen cause adolescent growth spurt and skeletal differences between the sexes:
  - Wider shoulders, larger bones, narrow pelvis in men
  - Wider hips, smaller upper body in women
- **Excesses in any hormones can cause abnormal skeletal growth**
  - Ex. gigantism or dwarfism
Robert Wadlow, world’s tallest man 8 ft 11 inches

Yao Defen, gigantess currently in treatment for pituitary tumor in China. 7 ft 7 inches 396 lbs
Response to Mechanical/Gravitational Forces

- Bones respond to muscles pulling on them (mechanical stress) and to gravity by keeping the bones strong where they are being stressed.

- **weight bearing activities** → **stronger projections where muscles/ligaments attach**

- **High rate of bone deposition in specific areas.**
What you don’t use, you lose. The stresses applied to bones during exercise are essential to maintaining bone strength and bone mass.
A joint is where two or more bones meet. Also known as an articulation.

Joints can be classified either by:
- the tissue that holds the bones together
- or the degree of movement they provide

- **Synovial joints** permit free movement.
- **Fibrous joints** and **Cartilaginous joints** have limited or no movement.
Fibrous joints are connected by dense connective tissue and have no joint cavity.
Cartilaginous joints are connected by cartilage and have no joint cavity.
Synovial joints have a synovial, fluid-filled cavity that surrounds the articulating bones.

Synarthrosis: Joints that do not provide any movement.
Amphiarthrosis: Joints that only provide a small degree of movement.
Diarthrosis: Joints that allow free movement.
FIBROUS JOINTS
In a fibrous joint, the two bones are connected by dense fibrous connective tissue. These joints can be either synarthrotic or amphiarthrotic.

There are three different types of fibrous joints:
Suture: between the flat bones of the skull
Gomphosis: The roots of a tooth and the alveolar sockets in the maxilla or mandible
Syndesmosis: interosseous membrane
Sutures

Sutural ligament

These joints are synarthrotic
Gomphoses occur only between the teeth and adjacent bone. In these joints, short collagen tissue fibers in the periodontal ligament run between the root of the tooth and the bony socket.

These joints are synarthrotic
Syndesmoses

These joints are amphiarthrotic
CARTILAGINOUS JOINTS
In a cartilaginous joint, the two bones are connected by cartilage. These joints can be either synarthrothetic or amphiarthrotic.

There are two types of cartilaginous joints:

**Synchondroses**: growth plate

**Symphyses**: intervertebral joints, symphysis pubis
Intervertebral joints

Symphyses mostly occur in the midline

Symphysis pubis
**Synovial joints**

Synovial joints are most commonly found throughout the limbs.

In order for the joint to be classified as synovial:

- Both adjacent bones participating in the joint must be lined with **hyaline cartilage (articular cartilage)**
- The joint is encompassed in a **capsule** that encases the joint cavity.
- The interior of the capsule is lined with a **synovial membrane** that is responsible for producing and secreting **synovial fluid**
- **Synovial fluid** lubricates the joint, which aids in reducing the friction between the bones’ ends as they articulate with each other
- Further reinforcement of the capsule is provided by **ligaments**, **tendons** and **skeletal muscle**

These joints are capable of a large range of motions and consequently, are the most susceptible to dislocations.
Gliding (plane) Joint
Example: shoulder and hip joints

Hinge Joint
Example: elbow and knee joints

Pivot Joint
Example: atlanto-axial joint

Saddle Joint

Ball and Socket Joint
Example: shoulder and hip joints
Ellipsoid Joint:
Example: wrist joint