

# Chapter 5

## Supportive Tissues

Support in Animals is carried out by **Cartilage** and **Bone**.

### A. Cartilage

#### 5.1. Nature of Cartilage

Cartilage is a highly resilient c.t that provides strength and support in areas of the body requiring a certain degree of flexibility. Cartilage has two types of cells:

- 1) Chondrocytes are the mature cells of the cartilage. Chondrocytes mature from chondroblasts.
- 2) Chondroblasts are the immature cartilage cells and are responsible for the production of fibers and ground substance.

During cartilage development this extracellular material combines with water to form a hydrated, amorphous gel termed the Matrix. It is the matrix which gives cartilage its properties of: resiliency, weight bearing capability, and high tensile strength. All types of cartilage develop either directly or indirectly from mesenchyme in a process called Chondrogenesis. During early chondrogenesis newly proliferating chondroblasts develop and will form cartilage. After the chondroblasts have secreted enough matrix components they will be completely surrounded by the matrix and become chondrocytes. The space in the matrix occupied by the chondrocyte is termed the Lacuna and also contains interstitial fluid.

#### 5.2.. Cartilage Growth

Developmentally cartilage arises from mesenchyme in two patterns: Appositional Growth and Interstitial Growth.

##### a] Appositional Growth

In appositional growth cells in the perichondrium will differentiate into chondroblasts which will secrete new matrix material. This new material is apposed to the preexisting cartilage and will add to its mass. The chondroblasts will eventually develop into chondrocytes. The perichondrium is a membranous structure forming the outer covering of cartilage organs. It has two layers:

- (i) The outer layer is a fibrous layer of dense irregular c.t. which gives strength and support to the cartilage organ.
- (ii) The inner layer is a cellular layer made up of a single layer of cells having chondrogenic potential.

##### b] Interstitial Growth

In interstitial growth chondrocytes within the cartilage undergo mitosis producing new chondroblasts which will secrete new matrix material. This process increases cartilage from within the cartilage organ, These chondroblasts will also develop into chondrocytes. Daughter cells from mitotic divisions tend to remain near one another forming small clusters termed Isogenic Groups. The cells within an isogenic group are all the daughters of the same original chondrocyte.

### **5.3. The Nature of Cartilage Matrix**

The components of cartilage matrix include a high component of fibers, and proteoglycans. Proteoglycans are a class of glycosaminoglycans. The proteoglycan chondroitin sulfate is particularly prevalent. Based on the intensity of staining during histo prep there are two regions of matrix recognized.

i] Territorial Matrix - an extremely basophilic region which immediately surrounds the chondrocytes. The greater degree of basophilic staining demonstrated by the territorial matrix may be due to a higher GAG content.

ii] Interterritorial Matrix - a weakly basophilic region located between cells and groups of cells. Due to the density of the matrix, cartilage lacks nerves and blood vessels. The chondrocytes are nourished by the diffusion of oxygen and nutrients through the matrix from the blood vessels in the perichondrium.

### **5.4. Types of Cartilage**

Cartilage classification is based on the amount of fibers and ground substance present as well as the types of fibers present.

#### **5.4.1. Hyaline Cartilage**

Hyaline cartilage is the most abundant and widespread class of cartilage. It is the "characteristic" cartilage. Hyaline cartilage forms the bulk of the embryonic skeleton. Hyaline cartilage is found in the adult in: nasal septum, larynx, trachea, bronchi, articular surfaces of joints, and the costal cartilages.

Functionally hyaline cartilage provides flexible support and weight bearing surfaces in joints. In addition it forms the framework of the developing embryo. It also provides a mechanism for bone growth (in terms of lengthening).

The chondroblasts develop directly from mesenchyme. The matrix is clear ("hyaline") in appearance. The ground substance is abundant and contains delicate type II collagen fibrils. The collagen does NOT form bundles and so are not as visible. The matrix also contains the proteoglycans chondroitin sulfate and keratin sulfate. As one ages calcium begins to infiltrate the matrix increasing it's rigidity and thus progressively reducing the cartilage's ability for interstitial growth. Further growth can only be appositional.

#### **5.4.2. Elastic Cartilage**

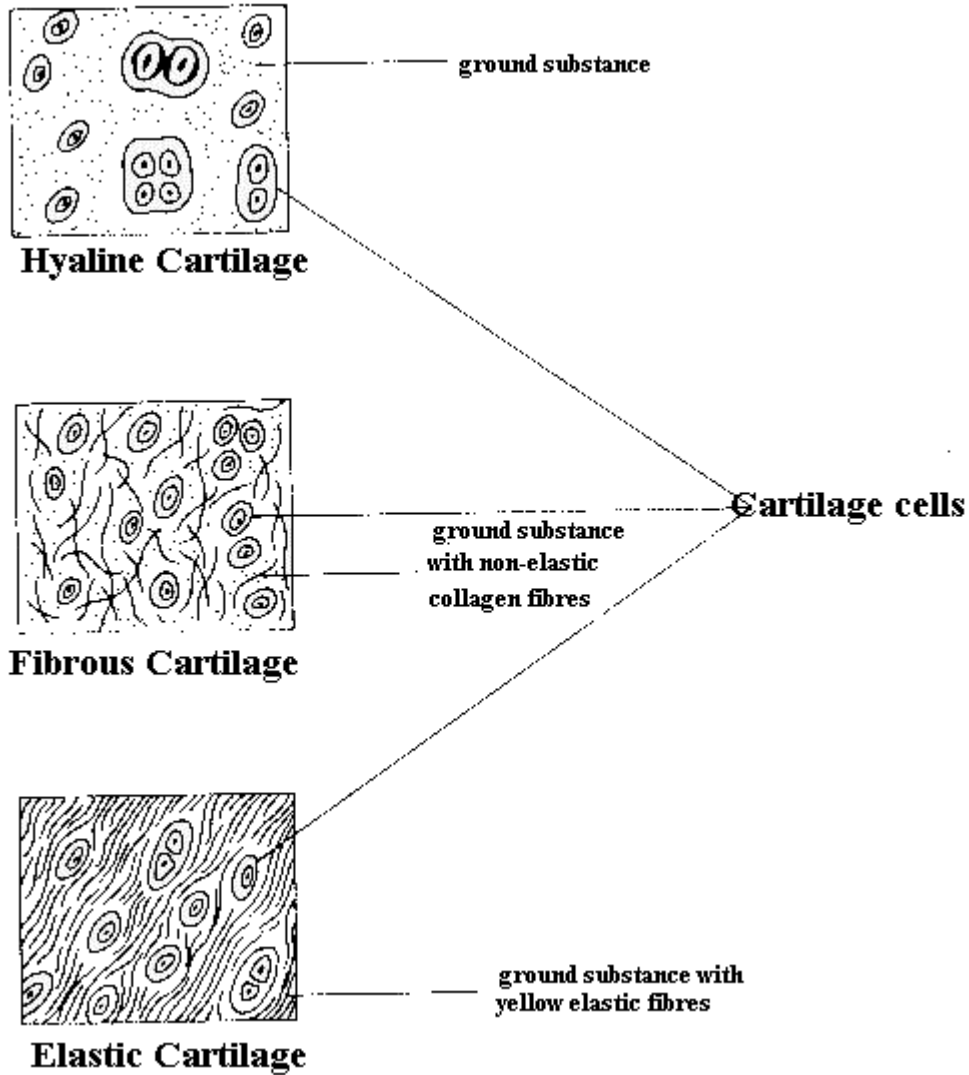
Elastic cartilage is considered to be a modification of hyaline cartilage. However, it's chondrocytes are derived from fibroblasts rather than directly from the mesenchyme. Elastic cartilage is found in: the external ear, auditory tubes, eustachian tubes, epiglottis, corniculate cartilages, and cuneiform cartilages. Functionally, elastic cartilage provides an extremely flexible support. The ground substance of elastic cartilage is sparse and extensively infiltrated with elastic fibers which are randomly arranged.

#### **5.4.3. Fibrocartilage**

Fibrocartilage is a combination of hyaline cartilage and dense regular connective tissue in both appearance and function. The chondrocytes, of fibrocartilage, arise from fibroblasts. The ground substance is extremely sparse and heavily infiltrated with dense collagen fibers arranged into parallel bundles. The chondrocytes are arranged into rows between the collagen bundles.

Functionally fibrocartilage combines the stress bearing properties of cartilage and tendons/ligaments for a firm, but not a rigid, support. It also allows for the repair of all types of cartilage. The repair of cartilage occurs by the formation of fibrocartilage. The

ability to repair our cartilages reduces as we age. Fibrocartilage is found in the intervertebral discs, pubic symphysis, and certain tendinous insertions (i.e.; the border between hyaline cartilage and dense regular connective tissue).



*Fig.5.1. Types of cartilage*

## **B. Bone**

### **5.5. Nature of Bone**

Bone can be considered to consist of "bone tissue" and "bone organs". Bone tissue is the mineralized supportive connective tissue forming the framework of bone organs. Bone organs provide the supporting framework of the body. As organs bones consist of bone tissue, external and internal connective tissue investments, tendinous insertions, ligamentous attachments, blood vessels, nerves and bone marrow (which consists of either bone forming elements or adipose deposits). In certain bone organs there are additional specializations for articulation. Bone tissue consists of cells, fibers, and ground substance as does any c.t. However in bone tissue the matrix becomes mineralized with

inorganic salts giving bone its rigidity.

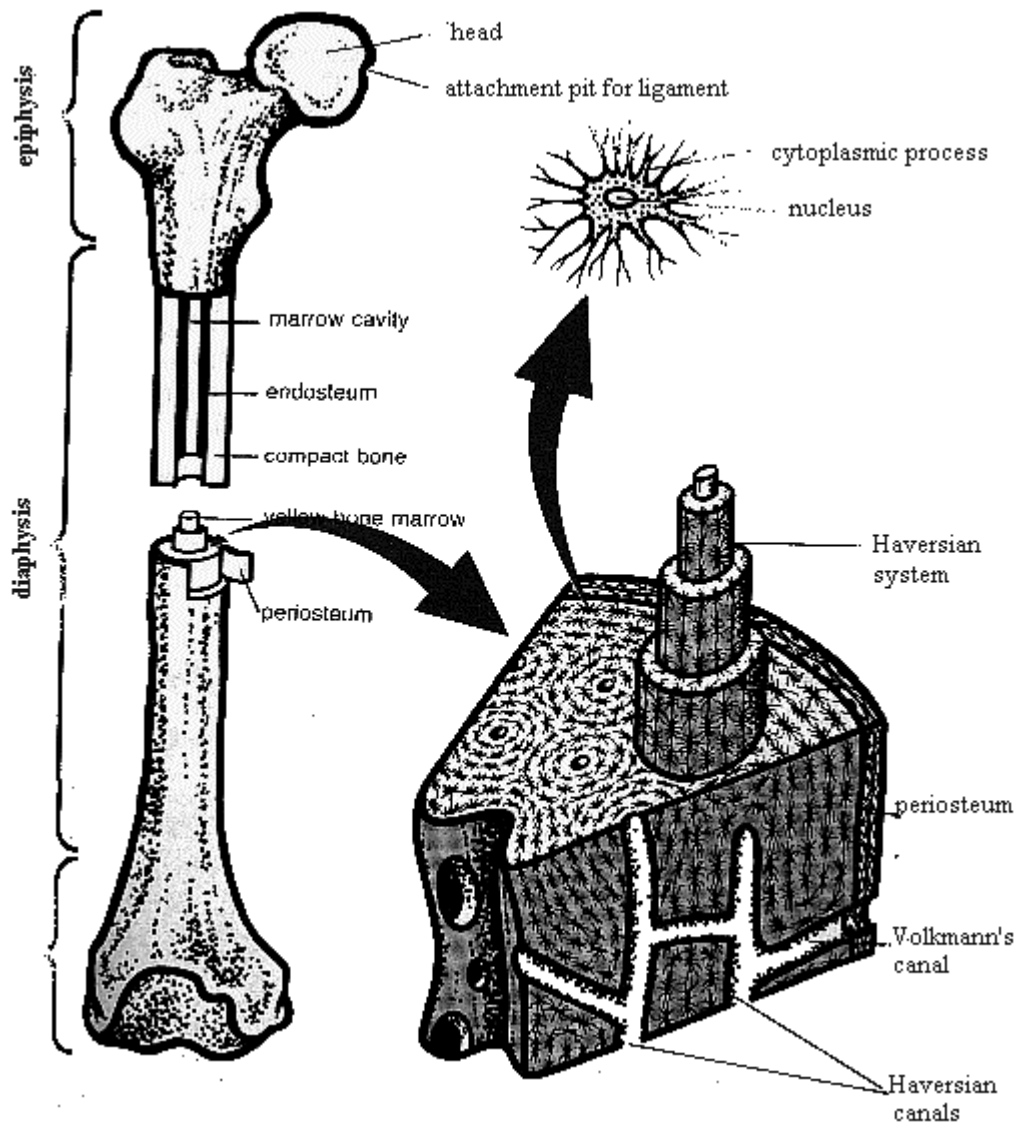
Morphologically bone tissue is organized in two ways: The two ways are:

**1] Compact Bone** - when the tissue forms a compact solid mass with relatively few intervening spaces.

**2] Spongy Bone** (aka; trabecular bone, cancellous bone) - when the tissue forms a three dimensional network of intercommunicating osseous projections termed "trabeculae".

General distribution in a bone organ for these two morphologies of bone tissue: Compact bone forms an outer protective shell for bone organs. This is called Cortical Bone.

Spongy bone forms a branching internal framework. This is called Medullary Bone.



*Fig.5.2. Structure of long bone with enlargement of a section of compact bone*

## **5.6. Organization of the Bone Organ (ex; the femur)**

### **5.6.1. Bone Tissues**

Compact bone forms the cortex of the epiphyses and diaphysis. Spongy bone forms an

internal supportive framework. In the case of the femur, a long bone, it is located within the epiphyses. The hollow core of the diaphysis, called the Medullary Space, is in direct communication with the cancellous spaces in each opposing epiphysis.

### **5.6.2. Bone Marrows**

Bone marrow occupies the intertrabecular spaces and the medullary cavity. In adults there are two distinct types of bone marrow:

a] **Red Marrow** - hemopoietic tissue located in the intertrabecular spaces that will give rise to blood cells throughout one's lifetime.

b] **Yellow Marrow** - an inactive, fat infiltrated tissue found in the medullary cavities of long bones.

### **5.6.3. Connective Tissue Membranes of Bone**

a] **Periosteum** - a layer of specialized dense connective tissue which covers the external aspect of the bone organ. (It covers the cortical bone.) Like the perichondrium, the periosteum has an outer layer of a fibrous nature and an inner layer of a cellular nature. This inner layer is made up of cells having an osteogenic potential. It will allow for the remodeling and repair of bone. Tendons and ligaments attach to the bone by way of the periosteum. The periosteum attaches to the cortical bone by means of Sharpey's Fibers (aka; Perforating Fibers). Sharpey's fibers are dense collagen bundles running from the fibrous layer of the periosteum into the mineralized bone matrix.

b] **Endosteum** - a layer of flattened cells having osteogenic potential lining the inner aspects of the bone organ (i.e.; medullary cavity, intertrabecular spaces, bone canals).

### **5.7. Blood Vessels Servicing the Bone**

In long bones, the vascular supply is from vessels that penetrate the diaphysis and marrow through the Nutrient Foramen/Nutrient Canal. These blood vessels arise from vessels of the periosteum. Nerves will often accompany the blood vessels. Within the bone tissue we see the Haversian systems. Enclosed in fluid-filled joint cavities, the articular surfaces of bone organs are covered by a cap of hyaline cartilage called Articular Cartilage.

## **5.8. Bone Tissue**

### **5.8.1. General Comments**

- 1) Bone tissue is a very specialized hard connective tissue of both complex structure and function.
- 2) In some ways bone is similar to cartilage in that it consists of cells and an intercellular matrix of fibers and ground substance.
  - a] However, certain cells induce the mineralization of bone tissue giving it a hardness and strength beyond that of cartilage.
  - b] Also, compared to cartilage, bone tissue has a high degree of structural organization in it's matrix.
    - 1] This is especially true in regards to the packaging of it's collagen fibers.
  - c] These two features allow bone to withstand and recover from tension and compression and to perform it's mechanical role with a minimum of weight and material.
- 3) Bone is a metabolically active tissue being continuously remodeled

throughout life and being capable of repair.

- a) This is accomplished by the resorption of old bone and the deposition of new bone.
  - b) Bone responds to mechanical stresses by reorganizing bone tissue to bear weight more efficiently.
- 4) Bone also serves as a reservoir for minerals, especially calcium and phosphate.

### **5.8.2. Constituents of the Bone Tissue Matrix**

- \_\_\_\_\_ 1) Bone matrix is a mineralized organic matrix.
  - a) The mineral component of bone matrix is termed Hydroxyapatite.
    - 1] Hydroxyapatites constitute ~65% of bone matrix volume and accounts for the rigidity and hardness of bone.
    - 2] The mineral component also serves as a reservoir for minerals (especially calcium).
    - 3] Although the matrix of bone primarily contains the minerals calcium, phosphate, carbonate, and citrate, other minerals such as fluorine, sodium, and magnesium also occur.
      - a} The principle bone mineral is calcium phosphate.
      - b} In some cases small amounts of harmful, radioactive minerals, which occur in the environment, can become incorporated into the bone.
  - b) The hydrated organic component bone matrix is termed the Osteoid.
    - 1] The osteoid constitutes ~35% of bone matrix volume.
      - a} 95% of the osteoid is collagen.
      - b} 5% of the osteoid is the amorphous ground substance consisting of proteoglycans such as chondroitin-4-sulfate and keratin sulfate.

### **5.8.3. The Cellular Component of Bone Tissue**

**a) Osteogenic Cells** (aka; osteoprogenitor cells) - are pluripotent stem cells, derived from mesenchymal cells, which can develop into either chondroblasts or osteoblasts. They maintain their pluripotent capability throughout life so as to allow for bone repair and remodeling. In the adult osteogenic cells are located in the cellular layer of the periosteum and in the endosteum.

Under the light microscope osteogenic cells appear as flat, inconspicuous cells with a pale staining, elongate nucleus and a sparse, eosinophilic cytoplasm.

**b) Osteoblasts** - are immature bone cells, derived from osteogenic cells, which will develop into osteocytes. Osteoblasts secrete the osteoid and participate indirectly in the subsequent calcification of the matrix. Once they have become isolated in the matrix which they have deposited, osteoblasts will undergo morphological changes and develop into osteocytes. In the adult osteoblasts are located in the cellular layer of the periosteum and in the endosteum as well as in the bone tissue itself where needed.

Since they are secretory cells, osteoblasts possess well developed rough endoplasmic reticuli and Golgi as well as many secretory vesicles. Under the light microscope osteoblasts appear as plump, polygonal cells usually having one side "attached" to the matrix which they are secreting. Their cytoplasm is extremely basophilic. One special group of secretory vesicles present in osteoblasts are called Matrix Vesicles. Matrix vesicles contain alkaline phosphatase. Alkaline phosphatase liberates phosphate ions

from organic phosphate by enzymatic hydrolysis. This allows for the calcification of bone matrix since it provides adequate amounts of organic phosphates to facilitate the precipitation of calcium ions. The phospholipids of the osteoblast's cell membrane bind to calcium to accelerate this process.

**c) Osteocytes** - are the principle cell type of bone tissue. They are derived from osteoblasts. Osteocytes exist in Lacunae surrounded by matrix in the bone. Bone matrix, however, does not allow for the diffusion of materials between the blood vessels and the osteocytes. Instead the lacunae have tiny radiating canals called Canaliculi. These canaliculi interconnect osteocytes since they allow cytoplasmic processes from osteocytes to reach one another. There are gap junctions between the osteocytic processes. The processes are surrounded by a nonmineralized intralacunar matrix. The canaliculi open up near blood vessels traveling through canals in the bone. So they serve to transport materials between the blood and the osteocytes.

**d) Osteoclasts** - are specialized cells of the bone which will degrade the matrix. The available evidence today indicates that osteoclasts are derived from circulating monocytes **not** from osteogenic cells as are the other bone cell types. Osteoclasts degrade bone at sites where the bone is being remodeled. The remodeling of bone is a twofold activity: Osteoclasts breakdown bone matrix in a process termed Osteoclastic Resorption. Osteoblasts secrete new bone matrix. (*NB: Osteoporosis occurs when osteoclastic resorption occurs at a greater rate than does osteoblastic deposition.*) Osteoclasts are also involved in the release of minerals from bone. Osteoclasts are generally located against the surfaces of bone where resorption is occurring. They are found in shallow depressions in the bone matrix which they have excavated termed

Osteoclasts are multinucleated, giant cells. The cell often has 30 or more nuclei. This is believed to be due to the fusion of monocytes during their formation. The cytoplasm of the osteoclast is acidophilic. The cytoplasm along the bone matrix is organized into an elaborate Ruffled Border. Electron microscopy indicates that this "ruffling" may be an array of villus like structures. Within the ruffled border is an area of cytoplasm rich in vesicles containing catabolic substances. Between the ruffled border and the matrix apposed to the osteoclast is a villus free zone called the Clear Zone. The clear zone anchors the osteoclast to the matrix.

## **5.9. Activities of Osteoclasts**

### **5.9.1. Osteoclasia or Osteoclastic Resorption**

Osteoclastic Resorption occurs in two stages:

**1} Demineralization of Bone** - the osteoclasts secrete one or more varieties of acids which increase the solubility of bone mineral salts along the ruffled border.

**2} Degradation of Collagen** - the collagen which has become exposed due to the demineralization of the matrix (located between the villi of the ruffled border) is degraded by the action of acid hydrolases released from osteoclast vesicles at the intervillar spaces. Bone resorption can occur during bone remodeling but also by a process called Osteocytic Osteolysis. In osteocytic osteolysis involves old osteocytes located deep in old, heavily mineralized bone. They are termed resorptive Osteocytes and will cause calcium to be released into the blood. This release of calcium occurring in osteoclasia is from superficial, less mineralized bone.

### **5.9.2. The Release of Calcium from Bone Matrix**

The release of calcium from bone matrix is under hormonal control.

1) Calcitonin, from the parafollicular cells of the thyroid gland, stimulate a decrease in osteoclastic resorption. Calcitonin reduces the size of the ruffled border and the size of the clear zone and decreases osteoclastic activity.

2) Parathyroid Hormone, from the parathyroid gland, stimulates an increase in osteoclastic resorption. Parathyroid hormone increases the size of the ruffled border and the size of the clear zone and increases osteoclastic activity.

## **5.10. The Arrangement of the Constituents of Bone**

### **1) The Arrangement of the Constituents of Bone in Spongy Bone**

Spongy bone demonstrates a relatively simple structure consisting of an interconnected network of bony bars (Trabeculae) with many intervening spaces (Intertrabecular Spaces). The bone tissue of the trabeculae is arranged into microscopic layers called Lamellae. This laminated structure is due to the orientation of the tissue's collagen bundles. The collagen of one lamella are all parallel.

The collagen within a lamella may all be parallel but they will also be at a 90° angle to those of the neighboring lamellae. This arrangement increases the strength of bone.

Located along the lamellae are the lacunae and their resident osteocytes. Radiating from the lacunae to the surface of the trabeculae are the canaliculi.

### **2) The Arrangement of the Constituents of Bone in Compact Bone**

The structure of compact bone is much more complex than is that of spongy bone mostly due to the problem involved in nutrients and oxygen reaching the osteocytes in this denser bone. There are three patterns of lamellar organization found in compact bone.

#### **i] Haversian Lamellae**

This is the most prominent of the three types of lamellae. Haversian lamellae consists of primary units of compact bone structure called Osteons or Haversian Systems. The osteon consists of lamellae arranged concentrically around a central canal. This blood vessel and nerve carrying canal is called a Haversian Canal or a Central Canal. The Haversian canal is lined with endosteum. The osteocytes, within their lacunae, are concentrically arranged around the osteon with their canaliculi radiating towards the Haversian canal and towards one another. Adjacent Haversian lamellae can connect with each other either directly or by canals perpendicular to the Haversian canals called Volksmann's Canals.

Volksmann's canals contain the branches of blood vessels and nerves traveling through the Haversian canals. Volksmann's canals are lined by endosteum.

#### **ii] Interstitial Lamellae**

These are fragments of laminated bone tissue that are packed between osteons. Interstitial lamellae represent remnants of older, partially resorbed and remodeled osteons. The boundaries between Haversian and interstitial lamellae are marked by Cement Lines.

#### **iii] Circumferential Lamellae**

Circumferential lamellae are circular lamellae forming the external and internal lamination of cortical bone. The outer circumferential lamellae are immediately below the periosteum and the Sharpey's fibers attach to it. The inner circumferential lamellae are immediately below the endosteum. The collagen bundles of the circumferential lamellae are perpendicular to those of the adjacent Haversian lamellae.

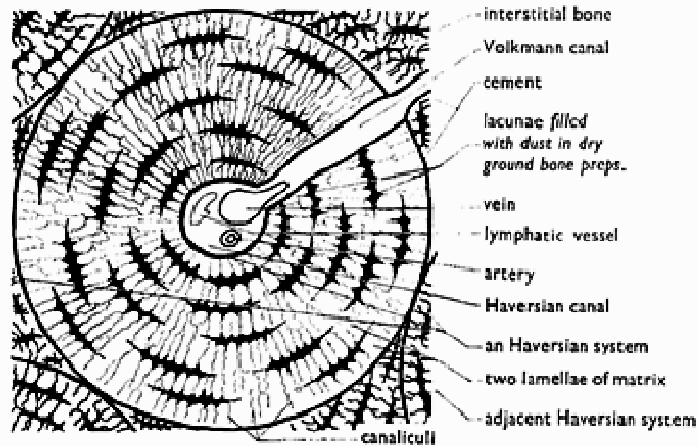


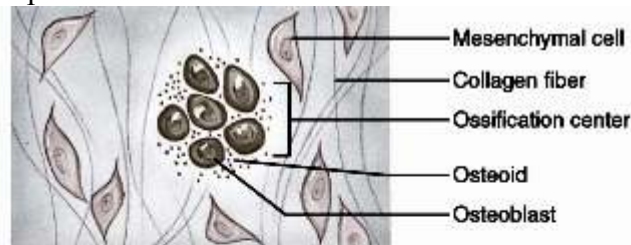
Fig.3.5. Drawing of the Haversian System

## 5.11. Osteogenesis

Osteogenesis (aka; Ossification) - Bone organs develop by two mechanisms:

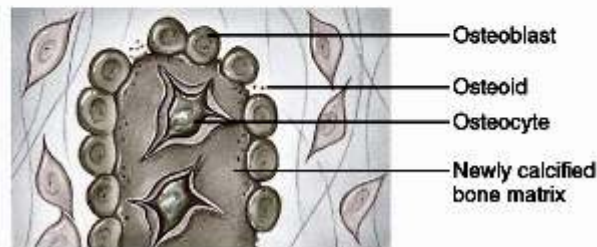
### a) Intramembranous Ossification

In intramembranous ossification a preformed model of the bone organ composed of mesenchyme is replaced by bone. So, in intramembranous ossification the development of the bone organ is initiated by the formation of bone tissue **without** a preexisting surface. The osteoblasts develop from osteogenic cells derived from mesenchymal cells and begin the process of osteogenesis. Intramembranous ossification occurs in the "Membrane Bones". Ex; frontal, parietals, clavicles, facial bones, portions of the mandible, occipital, and temporal bones.



① **An ossification center appears in the fibrous connective tissue membrane.**

- Selected centrally located mesenchymal cells cluster and differentiate into osteoblasts, forming an ossification center.

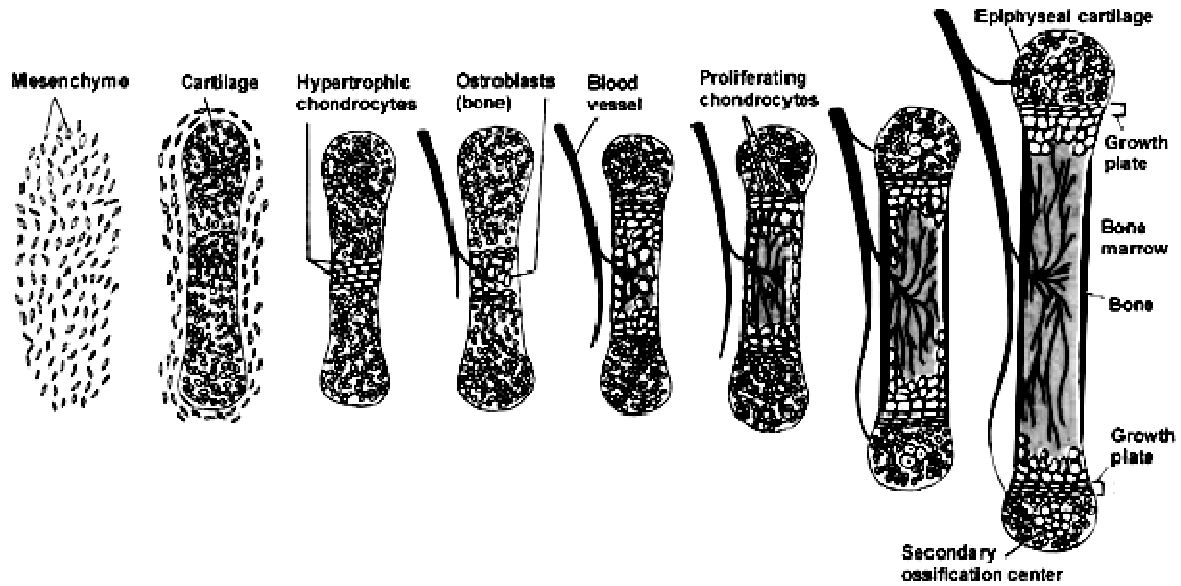


② **Bone matrix (osteoid) is secreted within the fibrous membrane.**

Fig.5.4. Endochondral Ossification

**b) Endochondral Ossification (aka; intracartilagenous ossification)**

In endochondral ossification a preformed model of the bone organ composed of hyaline cartilage is replaced by bone. In endochondral ossification development of the bone organ is initiated by the formation of bone tissue **with** a preexisting surface of hyaline cartilage. Endochondral ossification gives rise to the "Endochondral/Cartilage Bones". These are the majority of the axial and appendicular skeletal bones.



*Fig.5.5. Endochondral Ossification*