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Review Article

ANATOMY AND PHYSIOLOGY OF BONE – A REVIEW

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ABSTRACT
Bones forms the primary support structure for the human body. Although fundamentally comparable to other bone tissues in the body, alveolar bone is subjected to continual and rapid remodeling associated with tooth eruption and subsequently the functional demands is the ability of bone to undergo rapid remodeling is also important for positional adaptation of the skeletal system.

Key words:- Endochondral bone, Compact bone, Osteoblast, Osteocyte.

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INTRODUCTION

Bone is remarkably strong biologic construction material. It has a tensile strength comparable to that of cast iron, and it has a breaking stress point in bending that is intermediate between those of hard wood and cast iron. The properties of bone are more remarkable because it is a dynamic tissue, undergoing constant renewal in response to mechanical, nutritional and hormonal influences.[1]

Classification of Bone

Bone may be classified in several ways:

1. Developmentally, it can be classified into 2 types:
   (a) Endochondral bone – bone is preceded by a cartilaginous model which is eventually replaced by bone.
   (b) Intramembranous bone – bone forms directly within vascular fibrous membrane (Figure-1).
2. It can also be classified as:
   (a) Lamellar / Mature bone – collagen fibers are arranged parallel to each other.
   (b) Woven bone / Immature bone – collagen fibers are present in bundles that appear to run randomly in different directions (Figure-2).
3. According to its density, it may be categorized into 2 types:
   (a) Compact / Cortical bone – forms a dense, solid mass *(*Figure-3A).

Cancellous / Spongy bone – lattice arrangement of the individual bony trabeculae that surround soft tissue (Figure-3B).[2]

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Cell Types in Bone

Several cell types are responsible for synthesis, maintenance and resorption of bone (Figure-4). These can be regarded as belonging to two main families:

(a) Mesenchymal family – includes osteoblasts, osteocytes and bone lining cells which are derived from a mesenchymal stem cell.
(b) Hematopoietic family – includes osteoclasts which are derived from the mononuclear/phagocyte system.

Preosteoblasts

They have morphologic appearance of an inactive fibroblast, containing many free ribosomes, only a few profiles of rough endoplasmic reticulum (RER), and a small Golgi complex. During differentiation, they develop cytoplasmic polarity and greatly increase the amount of RER and Golgi complex.

Mesenchymal cell differentiation into the osteogenic cell line is preceded by the activation of *Osf2/Cbfa1* gene, which appears to serve as a master gene to turn on the expression of osteocalcin, osteopontin, bone sialoprotein and collagen synthesis. Experimental studies have demonstrated high levels of *Osf2/Cbfa1* expression in the developing maxilla and mandible as well as in tooth buds [2].

Osteoblasts

They are specialized fibroblast-like cells of mesenchymal cells origin. Active osteoblasts appear cuboidal and exhibit a basophilic cytoplasm that is related to extensive RER and large Golgi complexes within the cells.

Osteoblasts secrete collagenous and noncollagenous proteins and the proteoglycans of bone matrix, matrix metalloproteinases (MMPs) and their tissue inhibitors, various cytokine and growth factors, and soluble and insoluble forms of alkaline phosphatase.

They also express growth factors, chemokines and prostaglandins that act in an autocrine fashion to regulate osteoblastic activity and in a paracrine manner to influence other cells, especially osteoclasts. They also express receptors for vitamin D_3 and PTH that activate bone resorption and calcium mobilization.

During bone formation, osteoblasts become entrapped in bone matrix and are transformed into osteocytes.[3]

Osteocytes

They are contained in a lacunar space filled with bone fluid, unmineralized collagen fibrils and proteoglycans. There are about 25,000 osteocytes/mm^3 of bone. Once they have become fully entrapped in bone matrix, they exhibit diminished RER and Golgi complexes and few secretory granules.

They develop many cytoplasmic processes which occupy the small channels or canaliculi that are continuous with lacunar space surrounding the osteocyte. The lacunae and canaliculi form a space for the circulation of bone fluid from the deepest osteocytes to the osteoid layer.

During bone resorption, they are liberated from the bone matrix and engulfed by osteoclasts. They participate in calcium homeostasis.

Bone-lining cells

They extend flat cytoplasmic sheets over the bone surface. It is estimated that 80% of the total bone surface is covered by these cells. They act as gatekeepers, protecting the bone surface from osteoclasts, regulating the ionic composition of bone fluid and regulating the initiation of new bone formation or bone resorption. When stimulated, they divide and give rise to osteoblasts. Thus, they play an important role in responding to increased strain and in forming a fracture callus during bone repair.

Lamina limitans and cement lines

All inactive bone surfaces are covered by a thin densely stained lamina limitans. Cement lines demarcate successive layers of new bone formation.

Osteoclasts

These are the cells responsible for bone resorption. Resorbing surfaces of bone show resorption concavities (Howship's lacunae) in which lie the osteoclasts. The part of the cell that lies adjacent to bone and where resorption is occurring, often has a foamy, striated appearance which is known as 'ruffled border'.

They may be up to 100 µm in diameter and have on average 10-20 nuclei. The cytoplasm shows numerous mitochondria and lysosomes containing acid phosphatase. Their life span is thought to be about 10 to 14 days. The attachment of osteoclast cell membrane to the bone matrix is due to the presence of certain integrins (such as $\alpha v\beta 3$).

Bone resorption by osteoclasts occur in two stages – first the mineral phase is removed and later the organic matrix. [4].

Chemical Properties of Bone

About 60% of its wet weight is inorganic material, about 25% organic material and about 15% water. By volume, about 36% is inorganic, 36% is organic and 28% is water.

Organic matrix

It is made up of collagenous and noncollagenous proteins and proteoglycans. Type I collagen constitutes about 90% of the bone protein and it provides the structural framework to support the mineral phase. The noncollagenous proteins comprise remaining 10% of total organic content of the bone matrix which includes osteocalcin, osteonectin, bone sialoprotein, osteopontin and fibronectin. Two proteoglycans – biglycan and decroin – are also found in bone matrix.

Inorganic ions

The ions present are predominantly calcium and phosphorous (or phosphate). Magnesium, carbonate, hydroxyl, chloride, fluoride, citrate, sodium and potassium are also present in significant amounts. Most of the calcium, phosphate and hydroxyl ions are in the form of hydroxyapatite ($Ca_{10}[PO_4]_6[OH]_2$). These hydroxyapatite crystals lie parallel to collagen fibers and contribute to the lamellar appearance of bone.

The calcium salts present in bone are not ‘fixed’. When calcium level in blood rises calcium is deposited in bone; and when the blood calcium level falls calcium is withdrawn from blood to bring blood levels back to normal. These exchanges take place under the influence of hormones (PTH and calcitonin).

Histology of Bone

Osteoid

Any surface where active bone formation is occurring will be covered by a layer of newly deposited unmineralized bone matrix called osteoid. It has a thickness of approximately 5-10 µm before reaching a level of maturity. It consists of type I collagen fibers arranged more or less parallel to bone surface, embedded in complex ground substance of proteoglycans, glycoproteins and other protein molecules (Figure-5).

Under light microscope, osteoid will stain differently from that of matrix associated with mineralized bone indicating that, at the mineralizing front, biochemical changes take place within the matrix to enable mineralization to occur; some molecules may be added, others are degraded.[5]

Bone organization

Bone is deposited in layers or lamellae, each lamella being about 5 µm thick.

In compact bone, the lamellae are arranged in two major patterns. At external (periosteal) and internal (endosteal) surfaces they are arranged in parallel layers completely surrounding the bony surfaces as circumferential lamellae. Deep to circumferential lamellae, the lamellae are arranged as small concentric layers around a central vascular canal. The vascular (Haversian) canal, together with the concentric lamellae, is known as a Haversian system or osteon. There may be between 4 and 20 concentric lamellae within each Haversian system.

In spongy bone, the lamellae are opposed to each other to form trabeculae about 50 µm thick. The trabeculae are aligned along lines of stress so as best to withstand he forces applied to the bone while adding minimally to mass.

In the body as a whole, about 85% of bone is of the cortical variety while about 15% is spongy. Cortical bone is said to remodel about 3% of its mass each year, while spongy bone remodels about 25%. The cortical bone functions mainly in a mechanical/protective role, while spongy bone has a more metabolic function.

Alveolar Process

The alveolar process is the portion of the maxilla and mandible that forms and supports the sockets (alveoli) (Figure-6). It forms when the tooth erupts to provide the osseous attachment to the forming periodontal ligament; it disappears gradually after the tooth is lost.

The alveolar process consists of the following:

1. An external plate of cortical bone formed by Haversian bone and compacted bone lamellae.
- The inner socket wall of thin, compact bone called the alveolar bone proper. Histologically, it contains a series of openings (cribriform plate) through which neurovascular bundles link the periodontal ligament with the central component of the alveolar bone, the cancellous bone.
2. Cancellous trabeculae, between these two compact layers, which act as supporting alveolar bone.

Socket wall

The socket wall consists of dense, lamellated bone, some of which is arranged in haversian systems and bundle bone. Bundle bone is located adjacent to the PDL that contains a great numbers of Sharpey’s fibers. It is characterized by thin lamellae arranged in layers parallel to the root, with intervening appositional lines. Bundle bone is localized within alveolar bone proper (Figure-7).[6]

Bone marrow

Embryonal bone marrows are occupied by red marrow which is gradually replaced by fatty or yellow inactive type of marrow in the adults. Foci of red bone marrow are occasionally found in the maxillary tuberosity, maxillary and mandibular molar and premolar areas and the mandibular symphysis and angle regions (Figure-7). [7]

Interdental septum

The interdental septum consists of cancellous bone bordered by the socket wall cribriform plates of approximating teeth and the facial and lingual cortical plates *(Figure-7)*. If the interdental space is narrow, the septum may consist of only the cribriform plate. A study examined 116 posterior interproximal sites in 29 human cadavers and demonstrated that lamina dura was present between 89.6% of teeth where inter-root distances exceeded 0.5 mm and cancellous bone was absent and adjacent lamina durae were fused between teeth where inter-root distance was less than 0.5 mm.

The mesiodistal angulation of the crest of the interdental septum usually parallels a line drawn between the CEJs of the approximating teeth. The distance between the crest of the alveolar bone and the CEJ in young adults varies between 0.75 and 1.49 mm (average 1.08 mm). This distance increases with age to an average 2.81 mm [8].

Fig. 1 – Histologic section showing intramembranous bone

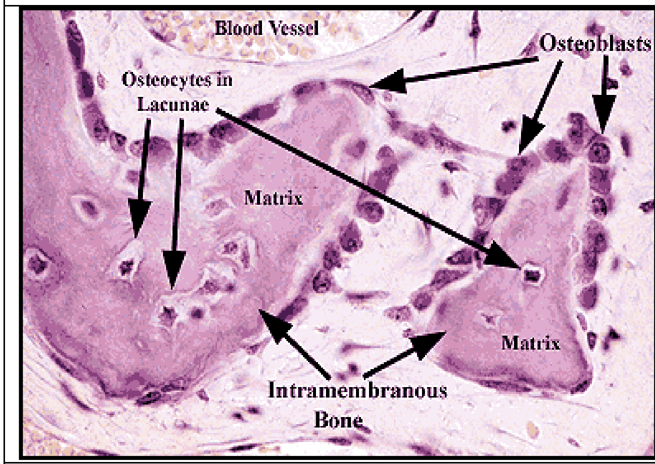


Fig. 2 - Histologic section showing lamellar (green arrow) and woven (black arrow) bone

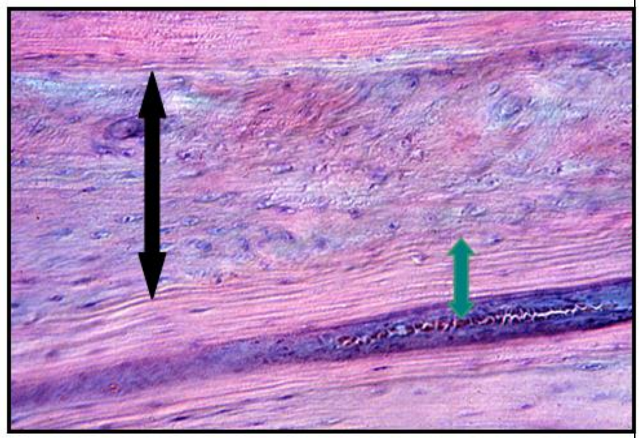
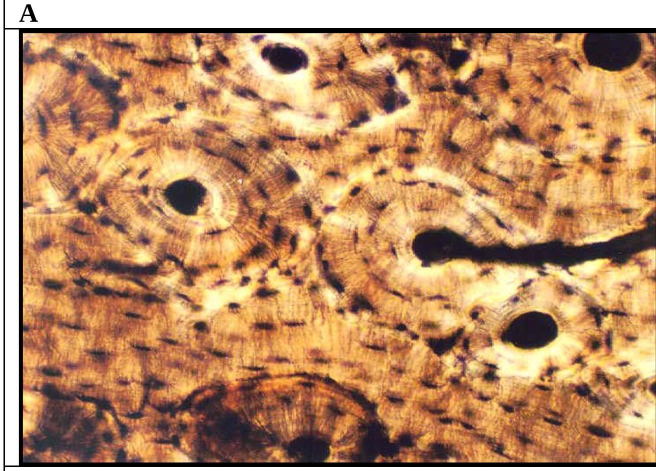


Fig. 3 – Histologic section showing compact bone (A) and cancellous bone (B)

A



B

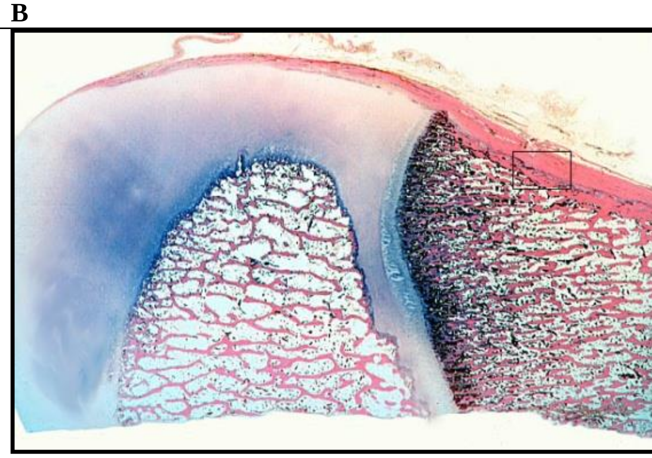


Fig. 4 – Cell types in bone (a - osteoclasts; b - osteoblasts; c - osteocytes, d - bone lining cells)

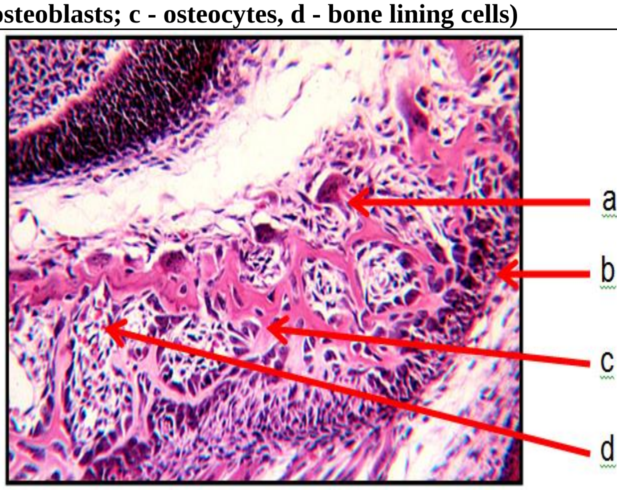


Fig. 5 – A Histologic section showing osteoid

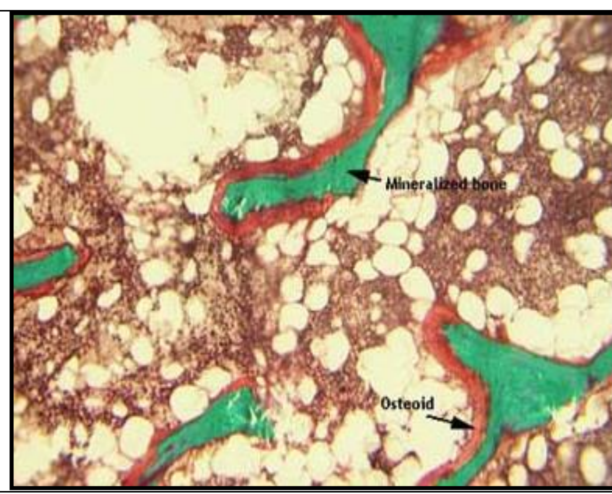


Fig. 6 – Macroscopic structure of alveolar process

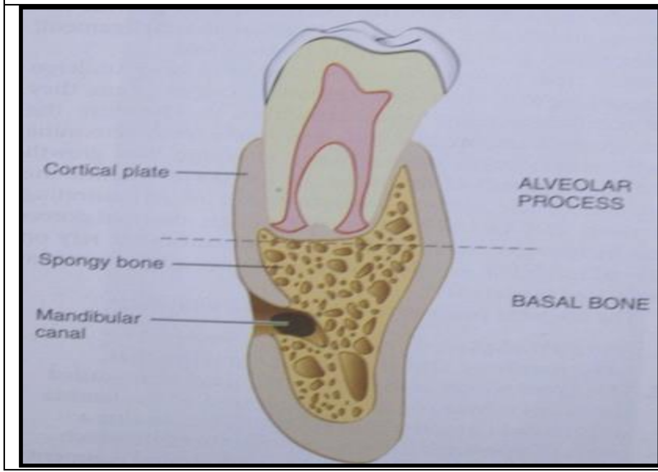
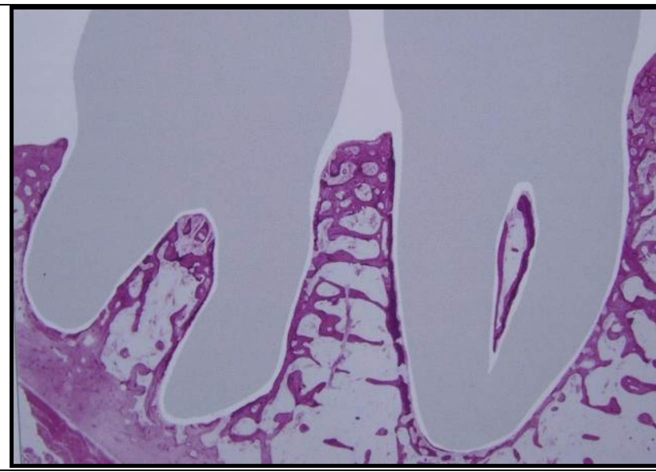


Fig. 7 – A histologic section showing interdental septum and socket wall



CONCLUSION

The total number of bones in the body is two hundred and six in number and each bone in the human body differs from shape to shape related to their function. The knowledge about the functional and molecular biology is essential for the better understanding of bone.

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