# A Résumé of the Histology and Formation of Bone*

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As orthodontists by far the greater part of our working time is spent in mechanical operations which, in the natural course of events, cause us to focus our attention on the purely clinical aspects of our specialty. However, since it is the reaction of bone, our basic medium, to mechanical force that permits orthodontic correction, it is important that we keep before us the realization that we are dealing with a vital tissue made up of living cells. Further, because the reactions of these cells definitely condition these forces and our clinical methods both must be modified in the light of research findings.

To aid this realization and further this application is the purpose of this brief review.

## GENERAL CONSIDERATION

Bone is essentially an organic framework that has been impregnated with calcium salts. The former, composing roughly about one-third of the whole, is identical with collagen of connective tissue while the balance, the inorganic portion, contains chiefly calcium and phosphorus.

As will be described in some detail, bones may have either a cartilagenous or a membranous origin. All long bones are first laid down in cartilage, as are the ethmoid, the major portions of the sphenoid and occipital, and part of the temporal bones of the skull. The remaining skull bones originate from connective tissue. The mandible presents an interesting departure from this schedule in that it has an early cartilaginous precursor, Meckel's Cartilege, which is replaced by connective tissue during osteogenesis.

Bone is of two types, cancellous (or spongy) and compact. Cancellous bone consists of a framework of bars enclosing spaces containing a soft tissue, the bone marrow. Compact bone, as its name indicates, is structurally dense and macroscopically reveals only the large central marrow space. Histologically the same elements are found in both types of bone.

According to their general form bones may be either long bones or flat bones. The greater part of the long bone is known as the shaft, or diaphysis, the articular extremities of which are the epiphyses. The shaft is compact bone and encloses the large marrow cavity containing the blood forming elements; the epiphyses consist of spongy bone enclosed in a thin layer of compact bone. The flat cranial bones consist of inner and outer layers of compact bone enclosing a central section of spongy bone called the diplöe.

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The maxillae and the mandible are structurally somewhat similar in that they also possess inner and outer layers of compact bone but these enclose much more bulk of spongy bone. A study of these varying designs and structural differences, if correlated with function, can be most revealing.

Histologically two methods are employed in studying bone. Thin ground sections may be prepared or the specimen may be subjected to an acid bath, after fixation, and stained. The former method preserves the inorganic portion while the latter preserves the organic cellular structure. A classic method of study involves the ingestion of madder which imparts a characteristic stain to the growing portions of bones but necessitates ultimate sacrifice of the animal. Another approach is implantation of metallic plugs which also requires sacrifice of the subject. Finally, bone may be studied roentgenographically; depending upon the means employed and the end desired, this may evaluate developmental growth or test the degree of mineralization. Today, every orthodontist should be familiar with the fundamental information flowing from studies employing combinations of all these methods.

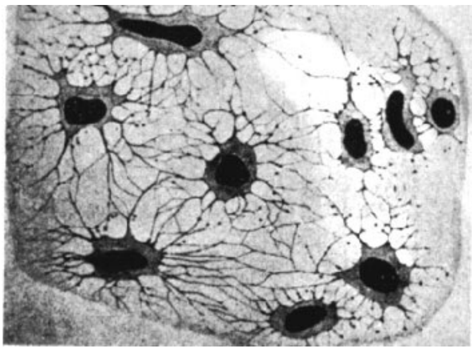

**Fig. 1**

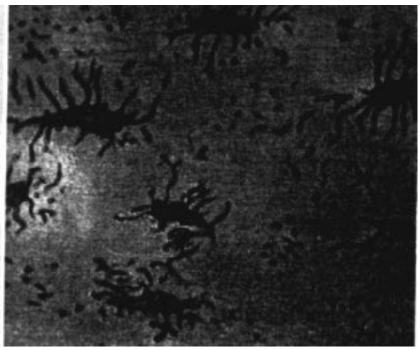

**Fig. 2**

BONE HISTOLOGY

The fundamental histological components of bone are cells and interstitial substance. (Fig. 1.) The cell, or osteocyte, is shaped somewhat like a watermelon seed from whose edges and surfaces extend protoplasmic processes. The cells lie in spaces called lacunae, which they completely fill. Their protoplasmic processes pass into the bone through tiny canals, the canaliculi, which anastomose freely with those leading from other lacunae. The canaliculi appear as dots when they assume a direction at right angles to the plane of the section.

The interstitial tissue consists of fibrils, known as osteocallagenous fibrils, and a binding substance. (Fig. 2.) It is probable that both fibrils and binding substance are impregnated with calcium salts.

When new bone is added to that already laid down, it is deposited in layers, or lamellae, so that the whole structure takes on a laminated appear-

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ance. The lacunae within the individual lamellae all run in the same general direction, parallel to the interstitial fibrils. The fibrils unite the lamellae and increase their strength considerably by passing from one lamella to another.

Passing in all directions through the compact bone of long bones but directed chiefly parallel to the length, are small blood vessels from the periosteum which have an important nutritional function for bone. Around these are grouped the lamellae in concentric arrangement. Their central cylindrical spaces, known as Haversian canals, give passage to these nutrient vessels and contain myeloid elements. Some of them end in the marrow cavity while others loop around and go back toward the periosteum. Where

Fig. 3

Fig. 4

the compact bone meets the spongy bone the canals broaden into the spaces between the spongy spicules.

A group of lamellae about a central canal constitute a Haversian system. (Fig. 3.) In a cross-section of a system, alternate lamellae have circularly arranged fibrils while those of adjacent lamellae run parallel to the long axis of the system and appear granular in cross section. Other fibrils extend in roughly spiral fashion to further unite the lamellae and strengthen the bone.

Passing around the outer and inner surfaces of the whole bone are systems of lamellae known as basic, or circumferential, lamellae. (Fig. 4.) They are penetrated by blood channels, Volkmann's canals, which pass directly into the Haversian systems. All the Haversian systems are clearly outlined and may be distinguished from one another by cementing lines. These lines represent binding substance devoid of cells or fibers. Small bundles of fibrils are sometimes seen to extend through the basic and interstitial lamellae and are known as Sharpey's fibers. They emerge from the periosteum and serve to affix it to the bone.

Lining the external and internal surfaces of the bone are two connective tissue layers, the periosteum and the endosteum. The periosteum sheaths the long bones except at the synovial or joint surfaces. It is not firmly ad-

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herent to the bone except at points where the Sharpey's fibers penetrate and become embedded in the bone. At these points, the large blood vessels, which supply the marrow tissue, enter the bone.

The adult periosteum consists of an outer fibrous layer and an inner osteogenetic layer. Normally, the adult periosteum contains no osteogenetic cells and has no bone forming functions. Under conditions of injury, as in fracture, however, undifferentiated cells soon multiply and become differentiated into osteoblasts and osteoclasts. Bone-formation then occurs. Periosteum can produce bone in other parts of the body, where the vascularity is rich, if some spicules of its bone or other calcified material are transplanted with it. Under certain conditions, particularly in the absence of a rich blood supply, it can produce cartilage.

The endosteum lines the inner or marrow surface of the bone and is similar in function and structure to the periosteum. Within the marrow cavity the myeloid tissue is composed of undifferentiated mesenchymal cells, loose connective tissue and many different types of blood-forming cells. The myeloid tissue lies within the Haversian canals and in the spaces of spongy bone as well, and fills all bone cavities.

## INTRAMEMBRANOUS BONE FORMATION

To the orthodontist, the chief importance of a study of the histogenesis or formation of bone, lies in its essential similarity to the bone reorganization which results from orthodontic tooth movement. Moreover, in natural bone formation, these tissue changes can be observed in a more simplified form, from their very soft tissue beginnings to the more complicated reconstruction of later bone.

Intramembranous bone formation involves a process whereby bone is formed directly from connective tissue. (Fig. 5.) The first signs of bone occur within a loose, relatively undifferentiated, connective tissue. Early undifferentiated mesenchymal cells are present. They represent an important potential factor in the bone formation that is about to occur in that they are probably identical with the material cells of all the connective tissue in the body. Their respective differentiations into fibroblasts, osteoblasts, chondroblasts and blood-cells give rise to all the somatic connective tissues. The particular form which their specialization takes is probably dependent upon localized environmental factors within the tissue. We know, for example, that the same cells can form either bone or cartilage, depending upon the presence or absence of calcium material and rich vascularity in the area.

These undifferentiated mesenchymal cells have large muclei with heavy-staining, chromatin granules. The cells are ovoid or spindle shaped and they have processes which connect one with another. As they begin to be differentiated, their cytoplasm starts to swell and forms granules and vacuoles of a secretory nature. The vacuoles push the nuclei to one side and a typical osteoblast is produced. The osteoblasts continue to be connected by their protoplasmic processes.

The fibers of the connective tissue between the changing cells become swollen due to secretions from the cells. The cells then lay down a new, semi-solid, interstitial mass which takes the place of the fluid, amorphous, ground substance of the connective tissue. This is the beginning of bone.

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When the osteoblasts become imprisoned in the bone, as bone cells, they become smaller due to the loss of their secretory material and each cell loses its swollen, irregular shape. It begins to look like a melon seed and lies within its lacuna in the bone. The processes extend through the canaliculi in the bone that has formed around them.

The new bone forms in bars or bands which are surrounded by osteoblasts. The original osteoblasts which formed these bars of bone now be-

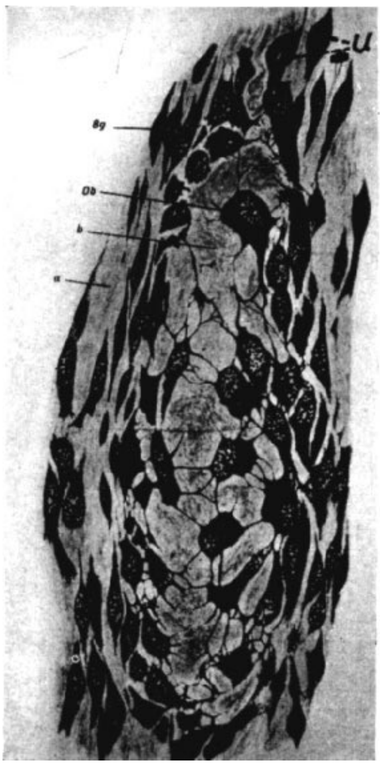

Fig. 5

Fig. 6

come the bone cells or osteocytes and are separated from each other by connective tissue fibers or periosteum. The bars become enlarged through the laying down of additional bone in layers by these surrounding osteoblasts. Small bands of bone meet and coalesce, thus forming a single large one.

In the formation of a membrane bone of the skull, such as the parietal, or the mandible, these bands unite to form the cortical plates of external compact bone. The spongy bone is formed by bars whose ends unite, leaving a mass of loose connective tissue within the bars. The peripheral osteoblasts lining the bone are continually being pushed outward. As new osteogenetic cells are required, their number is increased by specialization of the undifferentiated connective tissue cells from the peripheral connective tissue which may now be called periosteum. The osteocollagenous fibrils are at first ir-

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regularly strewn throughout the boney bars but as new layers of bone are added, they begin to take on the more definite arrangement described before in the section on histology.

### ENDOCHONDRAL BONE FORMATION

In the description of endochondral ossification, it is advisable to begin again with the loose connective tissue, where first the cartilage and then the bone is to be laid down. Ossification of a long bone will be described.

The mesenchymal cells in the center of the area where the bone is to be formed, become enlarged and differentiated into chondroblasts and begin forming cartilage. Along the periphery of this cell mass, the mesenchymal cells take on a specialization in another direction, becoming fibroblasts and forming the connective tissue of the perichondrium. Later, with the beginning of bone formation, the perichondrium becomes the periosteum. This is possible because the undifferentiated mesenchymal cells of the inner layer of the perichondrium can develop into osteoblasts rather than chondroblasts if a change in their environment favors this development. The cartilage formation proceeds from the center toward both ends of the future bone shaft. The perichondrium formation follows the same course.

The cartilage cells of the center of the mass show early evidence of degeneration. (Fig. 6.) The active site of cartilage growth in length now takes place nearer the extremities of the shaft. There the cartilage cells are younger and active mitosis occurs.

Thus, at this stage, we find a shaft of cartilage covered by perichondrium everywhere except at the articular extremities. In the center, where the cells are undergoing degenerative changes, calcification of the cartilage matrix occurs. At this time the cartilage of the center is hard and calcified while that of the extremities is young, active and proliferating.

About this time changes occur in the perichondrium connective tissue at the center of the shaft. Spaces develop which become lined with endothelium and are soon filled with blood. These are new blood vessels and they are formed in abundance. We now have two new environmental factors, the presence of calcified tissue and the rich vascularity which stimulate a change in the undifferentiated mesenchymal cells lining the inner surface of the perichondrium. They swell and become osteoblasts and begin to form bone immediately under the perichondrium.

The bone, which is formed at this time directly beneath the perichondrium is a thin layer that extends toward both extremities of the shaft. With this formation we may now refer to the perichondrium as periosteum. The thin layer of bone formed within the new periosteum is, strictly speaking, distinguishable from the bone which will soon be described. It is referred to as sub-periosteal, or periosteal bone, because it is formed directly by and under the periosteum. The bone formed within the disintegrating cartilage by an invasion of periosteal tissue at the center, is called endochondral bone.

The center of the cartilage is now invaded by the osteogenetic tissue. Many new blood vessels are observed as bone formation is initiated. Osteoclasts are formed which aid in the clearing up of the debris from the disintegrating calcified cartilage.

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An interesting observation in connection with the osteoclasts at this central location is that they begin to aid in the removal of some of the newly formed bone, so that remodelling of the bone itself has started almost before the bone formation has fairly begun. Secretions from the degenerating cartilage cells are thought to aid in the destruction of the cartilage. Ham[1] believes that the osteoclasts may not have an active osteolytic or resorbing function; they may simply represent giant multinuclear cells which are present to help in the removal of the masses of resorbed tissue.

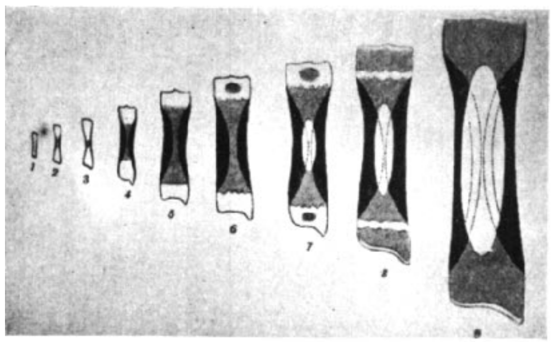

Fig. 7

Bone is laid down around the remains of the calcified cartilage spicules and the new bars of bone are lined with osteoblasts which continue new bone formation. Growth of the bone in lenth from this point depends upon the proliferation of the cartilage at the ends of the shaft. Endochondral ossification centers form at both epiphyses and there the cartilage is replaced by spongy bone which is covered by a thin layer of compact bone. In the epiphyses, as well as in the shaft, the articular ends remain as cartilage to permit growth of the bone in length until the shaft and epiphyses finally füse, when no further linear growth can take place.

Reorganization of the bone in the shaft occurs until that bone formed by the endochondral method is almost completely replaced by periosteal bone. The epiphyses, however, permanently retain the bone which has been formed by the endochondral method. In the course of this reorganization most of the spongy bone of the shaft is resorbed and its place is taken by compact bone. (Fig. 7.)

## CONCLUSION

A study of bone formation leaves a vivid impression of the malleability and plasticity of this tissue. The ability to respond so rapidly to remodelling forces according to need is remarkable when we consider that we are dealing with so hard and dense a tissue. It is this aptitude which we utilize in treatment and which is so important to us in achieving our results. Throughout bone formation it is the cells that have been most active. That certain

[1] Special Cytology: The The Form and Functions of the Cell in Health and Disease; Second Edition, E. W. Cowdrey, editor; New York, Paul B. Hoeber, 1932. Ham, A. W.: Cartilage and Bone, Vol. II, chapter 25, p. 979.

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chemical products from the blood and from these cells are important in the process is unquestionable but our viewpoint in appliance manipulation should be focused on these ultimate biological units. The forces used for tooth movement should be so controlled as to prevent overloading these cells and it is our future duty to discover more precisely how they can be applied to elicit the most beneficial cellular activity.

The essayist expresses his grateful appreciation to the editor and the publishers of *A Textbook of Histology* for so generously permitting the reproduction of all the illustrations used in this article.[2]

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[2] Maximow, A. A.: *A Textbook of Histology;* edited by William Bloom; Philadelphia, W. B. Saunders Company, 1931.

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