6-1960

Observations On Fibrous And Lamellar Bone

Harold M. Frost

OBSERVATIONS ON FIBROUS AND LAMELLAR BONE*

Harold M. Frost, M.D.

Henry Ford Hospital

INTRODUCTION

Pathologists routinely observe fibrous and lamellar bone.[a] Most pathologists instinctively learn to recognize the difference between the two kinds and often also learn the significance of fibrous bone in microscopic sections of skeletal material. Since no coherent literature deals with the subject[1,2,5,7,8], the student of bone pathology may remain long unaware of the existence and significance of the only two fundamentally different types of bone found in the skeleton. Recognition of the two types is essential for proper interpretation of osseous pathology.

In this paper some of the differences between fibrous and lamellar bone are outlined. The significance of the two in microscopic sections will be indicated.[4] The presentation is begun with a consideration of the "building blocks" of bone in order to orient the reader and establish the meaning of some terms.

THE CONSTITUENTS OF BONE[5,6,8]

Both fibrous and lamellar bone are composed of 4 major fractions.

The first fraction is the mineral moiety. This is composed of hydroxyapatite crystals which are about 300 Angstroms long and are composed of Ca, PO_4 and OH ions in a special type of lattice configuration. Adherent to the surfaces of the hydroxyapatite crystallites are varying quantities of additional ions including more Ca^{++}, $PO_4^{\equiv}$ plus $CO_3^{=}$, Cl^{-}, Na^{+}, K^{+}, Mg^{++}, citrate, some water (the hydration shell) and traces of other ions. The crystallites are regularly oriented with respect to the collagen in the matrix. This orientation produces much of the form birefringence present in undelcalcified bone sections. All of the above mineral is removed during decalcification of bone specimens and so is not observed by the pathologist on routine preparations.

The second bone fraction is the organic matrix. This is formed by osteoblasts and is composed of about 95% collagen, 5% mucopolysaccharide and traces of other proteins and organic substances. Collagen is orginally formed by the osteoblasts as protocollagen molecules of ultramicroscopic dimensions. After being excreted by the osteoblasts the protocollagen molecules polymerize and aggregate to form fiber bundles of sufficient size to be seen with the light microscope when properly stained. Obscure factors exist which affect the manner in which collagen condenses in the matrix. The presence or absence of these factors is responsible for the difference in formation leading to lamellar or fibrous bone.

The third bone fraction is composed of the cells, vessels and associated organic material normally found in the spaces present in bone. The spaces are the lacunae,

---

*Aided by Grant No. 293, Henry Ford Hospital Research Funds.

(a) Fibrous bone is variously referred to in the literature as woven, fetal, reactive fiber, immature and primitive bone. These terms all refer to the same substance which is termed fibrous bone in this paper.

canaliculae, Haversian and Volkmann's canals and the medullary space. While this material is the usual object of the pathologist's interest, it is not germane to the present topic and will be ignored henceforth.

The fourth bone fraction is the water normally present in the matrix and bone spaces. This too will be ignored in the following presentation.

We are now ready to consider fibrous and lamellar bone in detail and introduce the topic with:

PHILOSOPHICAL CONSIDERATIONS

Assume that a dump truck deposits a mess of brick, sand and mortar in somebody's yard. There is no overall architectural organization in this mess and this corresponds to the microscopic structure of fibrous bone. Assume that a mason is now hired who constructs a brick wall of the above materials. The finished wall has the same type, quantities and proportions of materials in it as the orginal mess but is now in a highly oriented architectural state. This corresponds to the microscopic structure of lamellar bone.

In summation then, fibrous bone lacks microscopic orientation while lamellar bone possesses microscopic orientation. The analogy falls down in two respects. First, it suggests that lamellar bone is somehow transmuted from fibrous bone when this is not the case. Both types of bone are formed *de novo* by osteoblasts and, once formed, are immutable. One type may replace the other only when the original type has been removed by osteoclasts; the other type is then deposited in the resulting bony defect. Second, the analogy suggests that the identical quantities, types and proportions of "building blocks" in fibrous and lamellar bone is experimentally verified. This is not the case. A great deal is known about the constituents of lamellar bone but little direct examination of fibrous bone has been done and its composition is *assumed* to be similar to lamellar bone.

As far as has been determined from morphology, histochemistry and routine staining behavior no difference between osteoblasts depositing lamellar bone and osteoblasts depositing fibrous bone has been observed.[1,2,3,4,5,8] Nevertheless there must be a difference in their chemical processes. Three cogent bits of evidence support this statement.

First, the structures of the end products are manifestly and consistently different.

Second, one may see fibrous bone being elaborated at one site in a section and lamellar bone being elaborated at another site by a different masses of osteoblasts in the same section but one never observes the same mass of osteoblasts forming both types of bone.

Third, the evolution of the skeleton depicts a clear demarcation between the two bone types. The first skeletons were hyaline cartilage. The second skeletons, representing the next evolutionary step, were of calcified cartilage. The third step in skeletal evolution was the elaboration of fibrous bone and its use to replace calcified cartilage. The final development was the elaboration of lamellar bone and its use to replace fibrous bone. Each of these steps of course represented a change in the chemical processes of the cells involved.

It is interesting and diagnostically useful that the above sequence of events still obtains in normal and pathological human material. When cartilage is to be replaced by bone it is first calcified, removed by phagocytic cells called chondroclasts and replaced by fibrous bone. Lamellar bone never replaces calcified cartilage directly. Fibrous bone in turn is replaced by lamellar bone under normal circumstances and in this simple fact lies the diagnostic usefulness of the distinction between fibrous and lamellar bone.

CHARACTERISTICS OF FIBROUS AND LAMELLAR BONE: MICROSCOPIC

(A) *FIBROUS:* The collagen in fibrous bone is present as a feltwork of collagen bundles. There is no consistent orientation of these bundles with respect to each other, to the long axis of the bone or to the loads on the part. As a result of this disorganization the pattern observed between crossed polarizers is that of the warp

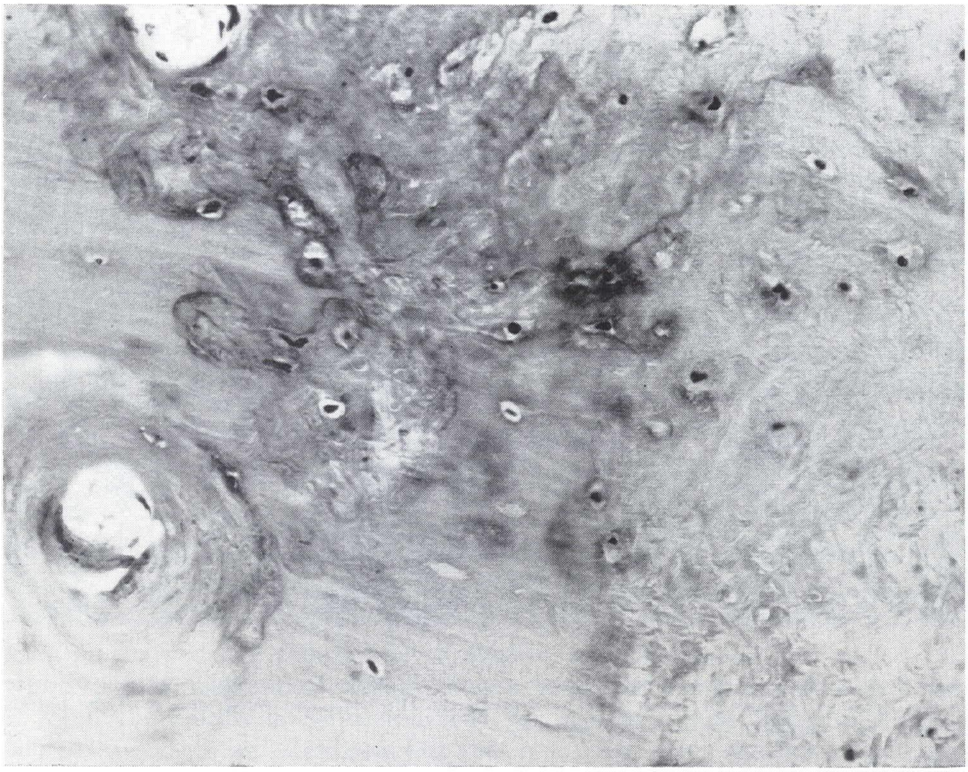

Figure 1

Bright field view of bone from a case of osteomyelitis of low grade severity and several years duration. A diagonal from the upper left corner to the lower right divides the field into two halves. The upper right contains fibrous bone—the black dots are osteocyte nulei lying in the lacunae, which appear as a lighter halo of varying shape and size around the nuclei. The lower left half of the photomicrograph is lamellar bone, with one Haversian system at 8 o'clock. There are fewer lacunae in the lamellar bone and the lacunae are elongated uniformly from left to right.

and woof of cloth, the bright lines being oriented 45° to the "X" or "Y" axes of vibration. A warp and woof pattern in bone examined between crossed polarizers is pathognomonic of fibrous bone.[4]

The lack of orientation of the collagen in fibrous bone is accompanied by lack of orientation of the lacunae in the matrix. Their long axes and flattened sides lie at any random orientation to the optical axis of the microscope. In addition there are considerably more lacunae per unit volume in fibrous bone than in lamellar bone and this difference is readily discernible on sections which contain both types (therefore equal thicknesses which make comparison of the number of visible lacunae per field valid). While there is a similar lack of orientation of the canaliculae, these are seldom apparent in decalcified material prepared in routine ways.[4] (Figs. 1,2,3,4,).

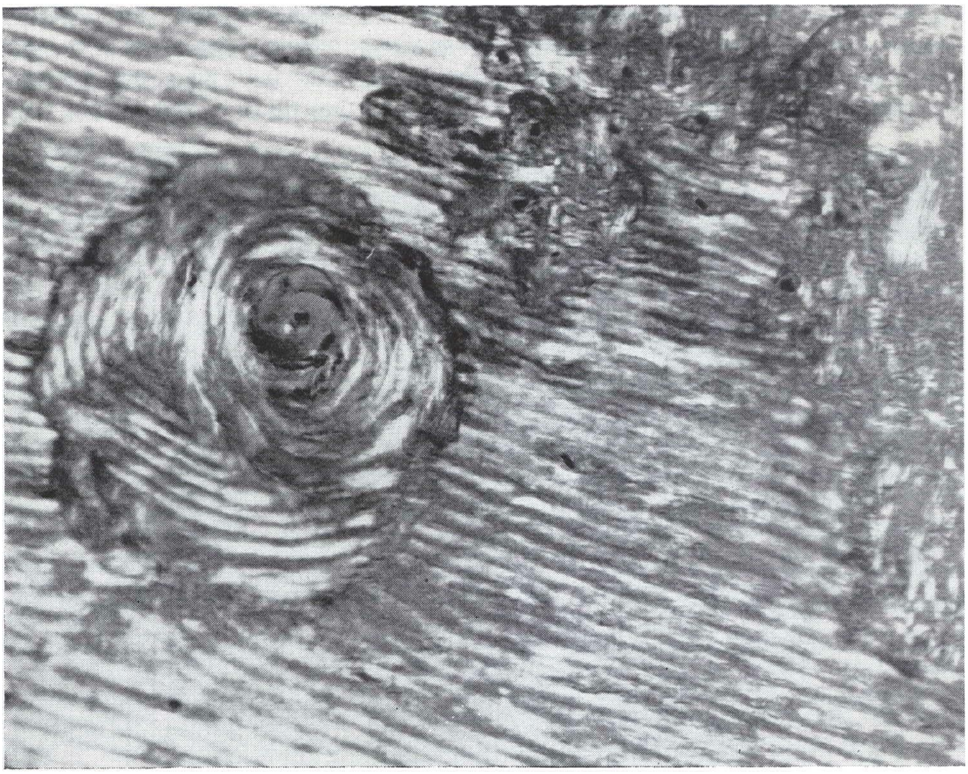

Figure 2

Same field as Figure 1, slightly higher power, crossed polarizers. The lamellar pattern in the bone in the center and to left of center may be appreciated. The warp and woof pattern of the fibrous bone at right margin is not as readily apparent.

Where fibrous bone is being actively formed another characteristic is evident: the irregularity of the surface of the trabeculae of fibrous bone.

The experienced microscopist readily recognizes fibrous bone by the lack of lacunar orientation, the increased numbers of lacunae in fibrous as compared to lamellar bone, the irregular borders of trabeculae, and the lack of any lamellar pattern

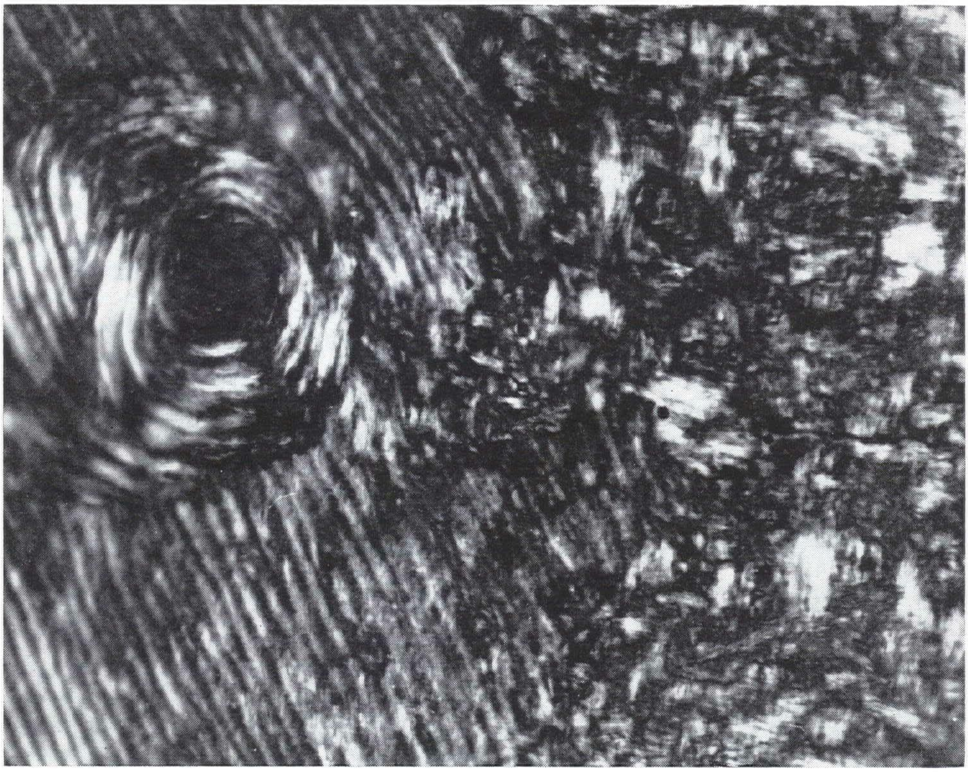

Figure 3

Same field as Figure 2, but rotated clockwise 45°. The warp and woof pattern of the fibrous bone in the right third of the photomicrograph is more clearly evident than in Figure 2.

when fortuitous staining reveals them or when the substage iris is reduced markedly below the numerical aperture of the objective being utilized (this produces a phase contrast effect which is more vivid when proper phase contrast equipment is utilized).

In embryos, fetuses and children the warp and woof pattern is finer than in adults and this has led to the designation fetal bone. Fetal bone is fibrous bone, not a different material.

(B) *LAMELLAR:* The collagen bundles of lammellar bone are finer than those of fibrous bone and are highly oriented with respect to the long axis of the bone, the loads on the part and with respect to adjacent collagen bundles. The result is the typical lamellar appearance between crossed polarizers which is illustrated. (Figs. 2, 3, 5). The lamellae in one bone moiety—for example a single Haversian system—will all have the same orientation with respect to each other. The factors governing this orientation are mysterious, intriguing, and have been the subject of much futile investigation to date. (Figs. 1, 2, 3, 5).

The lacunae in lamellar bone are also oriented, in effect seeming to be squeezed in between lamellae and with their long axes parallel to the long axis of the bone. The usually invisible canaliculae are similarly oriented but run from their lacunae of

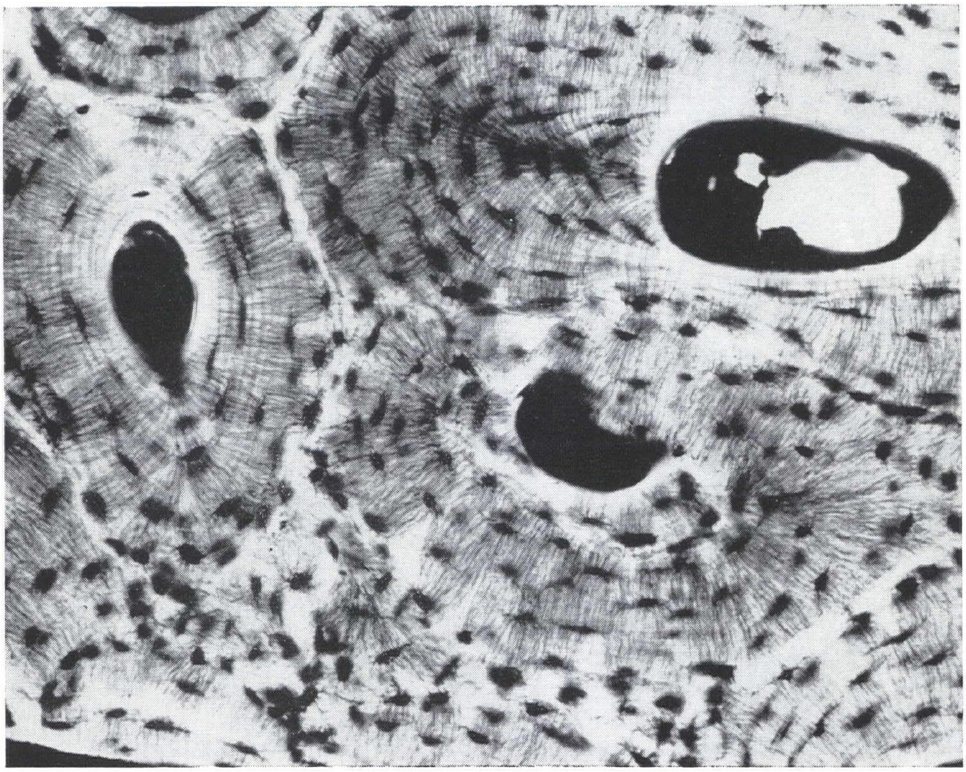

Figure 4

Stained, undecalcified cross section human femur. The high degree of canalicular and lacunar orientation in this section, which is almost entirely lamellar bone, may be seen.

At 8 o'clock about ½ way towards the center from the left margin there is a small fragment of fibrous bone whose lacunae and their canaliculae lack the orientation so apparent in the rest of the field. The cause, in this case, of the fibrous bone island was hypertrophic pulmonary osteoarthropathy during the last years of skeletal growth.

origin in perpendicular fashion through lamellae to a vascular channel. There are fewer lacunae per unit volume of matrix than in fibrous bone, the difference being by an approximate factor of 2. The borders of newly forming lamellar bone are smooth and lack the jagged irregularity which characterizes the borders of fibrous bone trabeculae.[4] (Figure 4).

PHYSIOLOGIC

(C) *FIBROUS:* Normally fibrous bone is found only in the epiphyseal plate of children and in the subchondral articular cortex of children and to a lesser degree of adults, and as a spotty layer between the bone cortex and the zone of calcified cartilage at the sites of tendon or fascial attachments to bone. Fibrous bone is the first bone to appear as a bony replacement of cartilaginous anlages in embryos and in the initial formation of membrane bones.[3,5] Fibrous bone which has an exposed surface—i.e.: a surface not covered by lamellar bone or calcified cartilage—is always replaced by lamellar bone. This process requires considerable time except during the growth process.[4]

Figure 5

Cross section human clavicle, crossed polarizers. The large, markedly oblate Haversian systems with eccentric Haversian canals (black, central oval spots) are typical of young adults. The circular lamellar pattern in the Haversian systems is outlined. The vertical lamellar pattern belongs to the circumferential lamellae. Medullary cavity lies to right.

Fibrous bone is nature's "solder" and in repair, neoplastic, inflammatory and irritative (or reactive) processes is laid down as a rapidly manufacturable material. When the stimulus to production of fibrous bone is mild, little of it is deposited and the trabeculae appear totally unoriented to each other initially. Remodelling processes may eventually produce considerable orientation however. When the stimulus to fibrous bone production is intense the trabeculae begin to show uniform orientation, typical examples being the trabeculae in the sun ray burst of an osteogenic sarcoma, or the onion peel reaction of an Ewing's sarcoma. Again later remodelling processes may considerably alter the initial orientation.

The presence of many haphazard cement lines in a mass of bone is evidence of considerable remodelling activity while lack of these cement lines indicates lack of remodelling. Lack of remodelling is usually due to ischemia or to the relative youth of the bony tissue examined.

Fibrous bone is typically seen in the following situations: normal and abnormal enchondral ossification during growth, elaboration of osteoarthritic osteophytes, ossification in enchondromas, chondrosarcomas and fractures; in infected bone; in repairing bone; as the layer of periostitis or "endosteitis" resulting from a host of irritating processes; and as a peripheral reaction or walling off to various inflammatory or neoplastic processes occurring in or adjacent to bone.

The presence of fibrous bone in other than the normal sites is a positive sign of some pathological process in the skeleton.[4] This sign is dependable even when, for example, biopsy material does not contain the vascular or cytological details and patterns permitting identification of the exact disease.

(D) *LAMELLAR:* This stuff is nature's preferred structural material because it is considerably stronger than fibrous bone. It cannot be elaborated quickly in large quantities. Even a single Haversian system, which is always formed of lamellar bone, requires from 3 to 10 weeks to form.[4] As noted above when fibrous bone exhibits free surface, it is always replaced by lamellar bone under normal circumstances. Thus, for example, the callus which heals a fracture, and which is composed mostly of fibrous bone, is eventually remodelled and replaced by lamellar bone. This process goes on for one or more years after clinical union and restoration of function. In the process small islands of fibrous bone become surrounded and covered on all sides with lamellar bone; in this state they may normally remain for many years. Observation of these surrounded, small islands of fibrous bone is observation of the evidence of some disease or repair process that occurred long ago. (Fig. 4).

The remodelling activity that is a normal part of childhood and adulthood consists of osteoclastic removal of old bone—be it lamellar or fibrous— and the replacement of the old with new bone. Normally this new bone is always lamellar bone. Consequently the osteoblastic activity which interests the endocrinologist, for example, is lamellar osteoblastic activity. The vicissitudes of lamellar osteoblastic activity in various diseases and under the influence of abnormal endocrine factors are not reflected in detectable similar vicissitudes in fibrous osteoblastic activity— another point in evidence that the chemistry of fibrous and lamellar bone formation is different.

SUMMARY

Fibrous bone is unoriented with respect to its collagen bundles and lacunar arrangement and contains more lacunae per unit volume than lamellar bone. Lamellar bone is highly oriented with respect to collagen bundles and lacunar arrangement. Fibrous bone is comparable to solder, quickly elaborated but to be replaced at leisure by lamellar bone which is a better structural material but is slowly elaborated. Normally fibrous bone is seen during growth in restricted areas. The presence of fibrous bone outside of these areas is evidence of a repair or disease process affecting the bone. The pattern of fibrous bone formation, the number of cement lines, and the amount of lamellar bone present yield significant diagnostic information to the pathologist.

REFERENCES

1. Aegerter, E. E., and Kirkpatrick, J. A., Jr.: Orthopedic Diseases, Philadelphia, Saunders, 1958.

2. Anderson, W. A. D.: Pathology, ed. 2, St. Louis, Mosby, 1953.

3. Arey, L. B.: Developmental Anatomy, ed. 4, Philadelphia, Saunders, 1941.

4. Frost, H. M.: Unpublished work.

5. Maximow, A. A., and Bloom, W.: Textbook of Histology, ed. 6, Philadelphia, Saunders, 1952.

6. Neuman, W. F., and Neuman, M. W.: Chemical Dynamics of Bone Mineral, Chicago, University of Chicago Press, 1958.

7. Snapper, I.: Bone Diseases in Medical Practice, New York, Grune & Stratton, 1957.

8. Weinmann, J. P., and Sicher, H.: Bone and Bones, ed. 2, St. Louis, Mosby, 1955.