of the osteoclasts is, and what their relation to the osteoblasts, we can, in the present state of exact knowledge, do little more than conjecture.

Consult, for the bibliography of the histology, development, and growth of bone, Quain's "Anatomy," vol. i. part ii., tenth edition, and the "Index Catalogue of the Library of the Surgeon-General's Office, U. S. A.," vol. ii.

T. Mitchell Prudden.

BONE. (PATHOLOGICAL.)—Bone, like all tissues, is subject to a continuous waste and repair. New bone is constantly formed and the old absorbed; and while in the adult these processes may be very slight, under the influence of pathological conditions they become very marked; hence the conditions known as pathological apposition, absorption, and transformation of bone. Apposition occurs by the formation of bone from the periosteum. The deeper layers of periosteal cells become converted into large epithelioid cells, the so-called osteoblasts, which later become irregular in shape; the intercellular substance becomes calcified and thus new bone is formed. The new bone may be spread out over the surface of the old, and become firmly attached to it, or it may be limited to a small portion of the surface of the bone. In the first case the process is called hyperostosis and exostosis; in the latter, the processes of new bone are called osteophytes.

Absorption or resorption of bone occurs at the medullary surface and is due to the activity of the large multinucleated cells known as osteoclasts. Occasionally this may occur at the periosteal surface, and we have the surface of the bone becoming irregular and porous—osteoporosis. This occurs occasionally in the very aged, in the bones of the calvarium, as the result of senile atrophy, or it may be secondary to inflammatory exudates, tumors, aneurisms, etc., which exert pressure upon the bone.

Transformation of bone is brought about by a combination of apposition and resorption. By means of these processes the form of bones is changed to meet pathological conditions and changes in function. This is more particularly true of the size and direction of the columns of bone in cancellous structures. If the amount and direction of the load to be borne by the bone become changed, then will the thickness and direction of the columns of bone become changed in the direction of the static demand. By reason of this characteristic of bone, such great artificial deformities are produced as are seen, for instance, in the Chinese foot.

Regeneration of bone is seen following every fracture. Every solution of continuity in bone is followed by the formation of new bone, not only sufficient to replace the defect, but also enough to form a large mass surrounding the fracture (callus).

In fractures of long bones, one differentiates an internal callus formed by the medullary structures, and an external callus formed by the periosteum. This new bone or callus remains intact until the function of the bone is resumed. Later on, that portion of the callus which is not situated in the direction of the load-bearing lines becomes absorbed, and the form of the new bone, just as that of the old, becomes changed to meet the static demands made upon it by the function of the bone—*i.e.*, that of bearing a load.

Osteomalacia is a chronic disease of bone, occurring in adults and most frequently in puerperal women; it is attended by a progressive softening and absorption of bone beginning in the centre and extending outward. The process is followed either by fracture or by deformity of the bones affected. It differs from rachitis in this, that while in the latter we have a deficient deposition of lime salts in newly formed bone, in osteomalacia bone which is already formed is deprived of its earthy material and absorbed. The changes that occur in the bone are not due to any active process on the part of the bone tissue itself. There are no active changes to be discovered in the bone cells. The only thing to be found in the lacunæ is the occasional presence of droplets of fat, which is evidence of a passive destruction of the bone cells.

In the medullary tissue, however, there are to be seen evidences of very marked, active proliferative processes. This is to be observed in the marrow of the long bones, in the medullary tissue of spongy bone, and also in the Haversian canals, which latter normally contain very little medullary tissue. This tissue is the seat of a marked hyperæmia which has converted it into a bright red, succulent tissue, free from fat and extremely rich in proliferating cells. All the medullary tissue seems to have the appearance of the red marrow of infantile bone. This tissue pushes its way outward at the expense of the adjacent bone, first depriving it of its lime salts and later causing its complete absorption.

Thus the compact bone of the diaphysis is converted into spongy bone by the enlargement of its Haversian canals; the trabeculæ of spongy bone are absorbed. If the process continue long enough there remains little of the bone except marrow and periosteum; so that it has been converted into a soft, decalcified, sausage-like mass of marrow, that is held together by the periosteum with perhaps a thin, paper-like layer of bone beneath.

The process may be distributed over a period of several years with occasional cessation. In such an event the medullary tissue loses its signs of active proliferation, the hyperæmia diminishes, and the tissue appears as a yellowish, fatty mass, or as a pale, gelatinous, mucoid, semi-fluid material. In the latter event many of the cells have undergone mucoid degeneration, and if this has been extensive it may have led to the formation of mucoid cysts. This period of quiescence may again give place to a renewed activity as before and to a further destruction of the bone.

This process has a certain resemblance, in activity, to that of inflammation, but the phenomena that attend either acute or chronic inflammation of bone are never present. We never find either suppuration or the formation of new bone.

The cause of decalcification of bone in this disease has been sought for chemically. Some investigators have found an excess of lactic acid in affected bones, and also in the urine, and the solvent action of this acid has been brought forward as the chemical agent which brings on decalcification. Other observers have failed to find this excess. The amount of gluten is diminished in the bones affected. There has been found in the urine a peculiar albuminous substance supposed to be derived from the organic substance of bone.

The bones of the pelvis and of the spinal column are most frequently affected, then come those of the thorax, and of the lower and upper extremities. The bones of the head are very rarely the seat of the disease; the teeth are never involved.

In the non-puerperal cases, the predisposing causes are malnutrition and living in dark, damp houses.

Osteomalacia has been observed in animals who are badly fed and stabled in dark, damp places.

Osteomalacia is a comparatively rare disease. It is rarely seen in England and America; it is more frequent in Germany than in France. In some parts of Germany the disease is more frequent than in others; thus in the Rhine valley and in Southern Germany the disease is more common than in other districts.

The preponderance of puerperal females affected is very striking. Thus of one hundred and thirty-one cases gathered together in the report of Letzmann, in 1861, eighty-five were in women who became ill either during pregnancy or during the puerperal period. Repeated pregnancy and prolonged nursing in poorly nourished women predispose to the disease.

In all of these puerperal cases the disease began in the bones of the pelvis, and in many it was limited to that region. It is therefore highly probable that the great circulatory changes in the pelvis attending pregnancy have a decided influence on the causation of the disease. Fehleisen regards the disease as a reflex trophoneurosis of the blood-vessels of bone, causing a dilatation and proliferation of the marrow at the expense of the bone, and having its origin in the ovaries. The removal of the

ovaries has been practised as a curative measure with some, though not universal success.

Of forty-six non-puerperal cases, thirty-five were in women and eleven in men. These cases are, as a rule, more rare than the puerperal.

Rachitis or *rickets* is a disease occurring in children. It is caused by improper food and bad hygienic surroundings, and is attended by a disturbance in growing bone whereby the reabsorption of bone is increased, the calcification of incompletely formed bone is diminished, and the formation of so-called osteoid tissue is excessive. It has been aptly and briefly described by Jenner as "an increased preparation for ossification but an incomplete performance of the process." The disease is most marked in the epiphyses of long bones and the margins of flat bones.

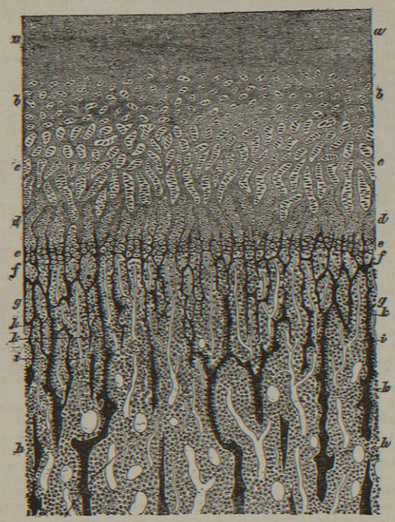

FIG. 647.—Section through the Line of Ossification of a Normal Femur from a Healthy Child. *a*, Hyaline cartilage; *b*, zone in which the cartilage cells are hypertrophied; *c*, cells arranged in columns; *d*, columns of hypertrophic cartilage; *e*, zone of temporary calcification; *f*, zone showing beginning of medulla; *g*, first bony formation; *h*, spongy bone; *i*, blood-vessels; *k*, osteoblasts. (After Ziegler.)

During the formation of normal, healthy bone there is always going on an absorption of already formed bone, which, however, remains confined to certain limits. In rickets the extent of this reabsorption is increased, so that in severe cases a large part of the bone may disappear. As a result, in the long bones the cortical layer becomes more or less osteoporous, and the columns of bone in the spongy portions become thinner and many of them disappear. This reabsorption of bone is lacunar, and, as in the case of normal bone, is due to the action of osteoclasts.

The most striking change is that which occurs in the epiphyseal ends of growing long bones. If one examines a section of the end of a normal long, growing bone (Fig. 647), a straight line may be seen where the white epiphyseal cartilage is joined to the cancellous shaft. The new bone is formed by a pushing of the medullary tissue from the cancellous bone into the epiphyseal cartilage. The two are joined by a straight, blue, semitranslucent band about 1 mm. broad, that is made up of hyperplastic cartilage, called the zone of growing cartilage.

Microscopical examination shows that in this area the cartilage cells have become greatly increased and are arranged in columns running parallel with the long axis of the bone. After these columns have acquired a certain height, there occurs at their base a deposition of calcareous material, which marks the cessation of the growth of cartilage. In a short time this calcified cartilage is destroyed by the pushing upward of the neighboring medullary tissue. These "buds" of medullary tissue, consisting of growing blood-vessels surrounded by a thin layer of medullary cells, push up between the columns of cartilage cells, gradually "eating" away the calcified, cartilaginous ground substance. The cartilage cells eventually disappear and are probably converted into medullary cells. Thus there are formed primary medullary canals bounded by the remains of the calcified cartilaginous ground substance, and it is this latter which then becomes converted into bone. This is brought about by the deposition within this substance of cells from the medullary canal which go to form the osteoblasts. The cartilage has formed the framework on which the growing bone has climbed, and is itself eventually absorbed.

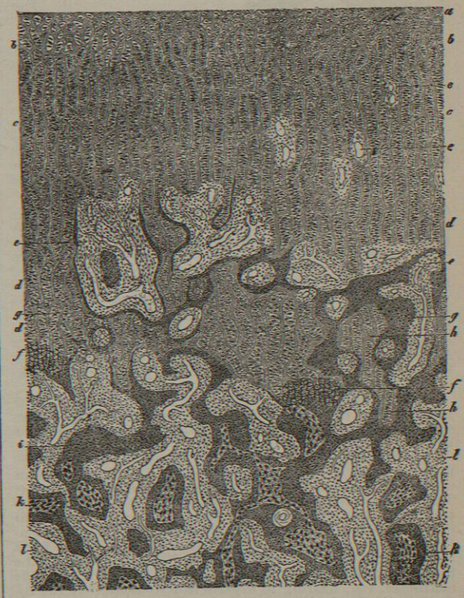

FIG. 648.—Longitudinal Section of the Line of Ossification in the Femur of a One-Year-Old Child Suffering from Rickets. (After Ziegler.) *a*, Hyaline cartilage; *b*, cartilage in the first stage of hyperplasia; *c*, zone of the columns of cartilage cells; *d*, columns of enlarged cells; *e*, vascularized marrow extending into the cartilage zone; *f*, calcified cartilage; *g*, osteoid tissue; *h*, remains of cartilage; *i*, columns of osteoid tissues; *k*, columns of osteoid uncalcified tissue, surrounded by true bone; *l*, vascular marrow tissue. (× 37 diameters.)

In rachitic bone, the blue transition zone of hyperplastic cartilage is much wider, while its outline, both

above, below, and at the circumference, is enlarged and irregular. It is this which forms the irregular enlarged ends so characteristic of the disease. The zone of hypertrophied cartilage cells as well as the columnar zone is enormously enlarged. There is also a more or less complete absence of the zone of calcification of the cartilaginous groundwork, and in addition there is a great irregularity in the formation of the vascular, medullary

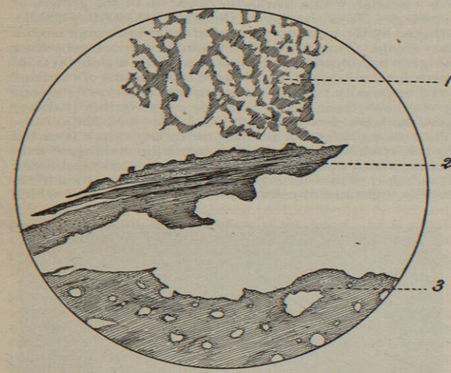

FIG. 649.—Necrosis and Inflammatory Hyperplasia of Bone. (After Boyce.) 1, Spongy new bone; 2, remains of shaft; 3, sequestrum. (Slight enlargement.)

canals. These have pushed their way into the cartilage in an irregular manner as though unrestrained by the presence of a firmly calcified groundwork.

The persisting columns of cartilage are gradually converted into an "osteoid" tissue, made up of cells derived from the medullary tissue and a fibrillar, uncalcified groundwork. This osteoid tissue will show in numerous places islands of persisting cartilage. The zone of osteoid tissue may attain a length of 15 mm.; it is a firm, elastic connective tissue, but it bends under pressure. It differs from bone in that the cells have not the same regularity of arrangement, and in the absence of earthy material in the groundwork.

At a varying distance below this zone we finally come upon a zone in which columns of osteoid tissue are becoming converted into bone by the calcification of the groundwork.

Inflammations of bone occur in the periosteum, in the marrow, or in the joints; that is, always in those portions of the bone which are well supplied with blood-vessels. They are as a rule due to hæmatogenous infection or to trauma, although occasionally they may be brought about by extension from neighboring tissue. If the inflammatory process is of any considerable degree, or lasts for a considerable time, it is always followed by changes in the bony substance itself. This, as a rule, is of a retrograde character, *i.e.*, leading to destruction of bone. If the inflammation is of a highly infectious, purulent character, the connective tissue affected becomes dissolved, the vessels become thrombosed and are destroyed, and the bone becomes necrotic. If the inflammation is less severe in character, if it is accompanied by considerable cell infiltration and the formation of new vessels (granulation tissue), there follows a gradual solution of the neighboring bone or cartilage, an ulceration, or, as it is usually called, caries. As long as this inflammation keeps up, so long is there a gradual absorption of the neighboring bone or cartilage. If in the beginning of the inflammation there occurs necrosis of a certain portion of bone, there follows in the later stages, at the surface of this necrosed portion, a gradual absorption which has its greatest intensity at the border between living and dead bone, so that eventually the two become separated and there is formed a sequestrum. If the latter is not very large it may in the course of time become completely absorbed by the neighboring granulation tissue. Large sequestra, however, offer a great deal of resistance to this absorptive process and may remain for years. As long as the sequestrum is present so long will the inflammation keep up, even though the infection has been overcome. A piece of dead bone acts as a foreign body and is a sufficient irritant to keep up this chronic form of inflammation.

In addition to this destructive process in bone accompanying inflammation, every such process lasting for any considerable time is accompanied by a hyperplasia, which manifests itself partly in the vascular soft parts and partly in the bone itself. This occurs both in the immediate neighborhood of the inflammation and in surrounding portions of the bone. It leads to those processes which have received the names of hyperostosis, exostosis, osteophytes, and parostosis. The most excessive hyperplasia of bone occurs in those cases in which a large sequestrum remains as a source of irritation for months and years.

Of acute infections, *osteomyelitis* is the most severe acute inflammation of bone with which we have to deal. It occurs most frequently in young individuals, as a rule in one of the long bones, and is accompanied by fever, by a destruction of more or less of the bone, and by the formation of an abscess. The infection is either primary or secondary to one of the acute infectious diseases. As a rule, the immediate cause is the staphylococcus pyogenes aureus or albus. The process may begin either in the periosteum, or in the marrow of the bone. It very soon leads to the formation of pus and to the destruction of bone. In severe cases it may lead to the suppuration of the marrow of the entire diaphysis and to an extension into the cortex of the bone through the Haversian canals. It may occasionally break through the periosteum. If the inflammatory process is near a joint, the pus may be poured into the cavity thereof. Through the formation of septic thrombi in the veins, we may have multiple metastatic abscesses and death by pyæmia. Wherever we have had a suppurative inflammation, there is of course a death of more or less bone, but the extent of this necrosis depends upon that of the suppurative process. If this has been very slight, the necrosed pieces of bone may become absorbed, so that they may not be discovered. In more severe forms we may have a sequestrum comprising the entire diaphysis. According to the extent and seat of the necrosis there may be distinguished a total, a partial, a central, and a superficial necrosis. Very soon after the setting in of the suppurative process there will be formed at the border, between the dead and the living parts, a zone of granulation tissue. This leads eventually to the separation of the sequestrum. When this has become complete there will be present, within the bone, an abscess cavity containing a sequestrum. This cavity very often connects with the surface of the bone by means of an opening or fistula. The walls of this fistula are also covered by a layer of granulation tissue from the surface of which pus is being poured out. In the neighborhood of these areas of granulation tissue there will have occurred more or less hyperplasia of bone which leads to a thickening. If the bone has been destroyed in its entire thickness in the beginning, then this hyperplasia occurs of course only in the periosteum, which thus surrounds the sequestrum with a firm, bony capsule. In cases of partial necrosis, however, new bone is formed both from the periosteum and in the interior of the bone. Small sequestra may in the course of months be absorbed; large ones constitute an irritant sufficient to maintain an inflammatory process for years, and they can be gotten rid of only by operative procedure. After the removal of the sequestrum the wound cavity is closed by means of granulation tissue, which later may be replaced by the formation of true bone through the activity of the periosteum or of the bone marrow.

Tuberculosis of bone gains entrance either through the marrow, the periosteum, the joint, or the surrounding soft parts. The most frequent method of development is that of a small tuberculous nodule which forms in the marrow of an epiphysis. This undergoes caseation and softening and eventually breaks through the bone to the surface, thus either entering into the joint or breaking through the periosteum. The process is of course always accompanied by caries, at times of considerable extent. A notable example of this is seen in tuberculosis of the spine, where the bodies of one or more vertebræ may be destroyed. This of course leads to the extensive deformities that we see in this disease (Pott's disease). After such a bone abscess (for this it really is) breaks through the periosteum, there are formed collections of pus in the surrounding tissues, particularly between the muscles. These sometimes reach an enormous size, and may through the influence of gravity dissect their way for a considerable distance through the body before reaching the surface.

In miliary tuberculosis, we have numerous tubercles in the bone marrow. Occasionally the tuberculous process affects the long bones of the hand or the foot in a very

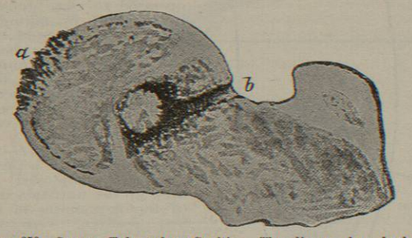

FIG. 650.—Severe Tuberculous Coxitis. The disease has broken through the cartilage at *a*. In the region of the neck is a sequestrum about the size of a cherry stone lying free in an abscess cavity connected with the joint by means of the fistula *b*. (After Krause.)

slow and chronic form, leading to resorption from the internal surface and apposition at the periosteal surface, and in this way producing certain peculiar spindle-shaped swellings that have been termed spinæ ventosæ. This may be followed by the occurrence of necrosis and the formation of sequestra and fistulæ, but in most instances the swelling eventually disappears.

Syphilis occurs in bone in three forms:

(1) Gummatous formations affecting both the periosteum and the marrow. In the periosteum, the process is accompanied by a destruction of bone, of such a character that sharply defined defects are produced—the so-called caries sicca. This occurs more especially on the calvarium. Occasionally one finds in the neighborhood of these bony defects new growth of bone.

(2) Hyperostosis. This occurs either in the form of hard, ivory-like thickenings in the compact bone, or in the formation of irregular exostoses or osteophytes. The latter form is found more especially in the tibia.

(3) Congenital syphilitic osteochondritis. This in its severe form is accompanied by the formation of irregular growths in the zone of growing bone, growths which have undergone a fatty and calcareous degeneration, and which may have the character of true gummata. In the lighter forms we have simply a calcification of the zone of cartilaginous hypertrophy at the epiphysis, marked by a sharp, yellowish-white line, and accompanied by a slight sclerosis of the neighboring bone. This affection is always present in congenital syphilis, but may disappear, so that a few weeks or months after birth it may not be found.

Actinomycosis of bone begins, as a rule, in the marrow by the formation of granulation tissue, which causes an absorption of bone from the inside and is accompanied by an apposition of bone on the periosteal side. In this way we may have large projections from the surface of the bone which, in decalcified and macerated preparations, will show on the inside the formation of a number of cysts. At times the actinomycotic process pushes through the bone to the periosteum, destroying this without being accompanied by the apposition of new bone, so that there will be produced a caries in the form of an osteoporosis.

Sarcomata are frequently found in bone. They occur either in the marrow (myelogenous sarcomata) or in the periosteum (periosteal sarcomata). Those that occur in the marrow of the bone produce, by the absorption of bone from the inside and apposition of bone from the outside, enlargements of the bone which attain at times enormous size, and in which we have the tumor mass surrounded by a more or less well-developed capsule of bone. Later on, even this capsule becomes either partially or totally destroyed by the pushing of the tumor through the bone. The tumor is as a rule of the round-celled variety, containing usually a large number of multinucleated giant cells. These giant cells may at times attain such enormous size as to be visible to the naked eye. Occasionally, however, they may be entirely absent. These sarcomata are exceedingly apt to recur after an excision or amputation. Periosteal sarcomata have, as a rule, a very considerable framework of bone in which the sarcomatous masses are enclosed, so that they are more aptly termed osteo-sarcomata. Occasionally also they have in addition a certain amount of cartilage, when they are called osteo-chondro-sarcomata. They are, as a rule, of the spindle- or small round-celled variety without giant cells. They are exceedingly apt to form metastases, especially in the lungs. *Simon Pendleton Kramer.*

BONE, PLASTIC SURGERY OF THE.—Defects in bone heal so slowly and imperfectly that it is no wonder surgeons of very early times tried to assist nature in their repair. There is some reason to suppose that such efforts were successful in India more than five hundred years ago, while a Peruvian skull antedating no one knows how long the discovery of America has, according to McGee, been found with a silver plate sunk in its substance to protect the opening made after trephining. The condition of the bone shows that the plate rested in it for a considerable time before death.

Despite this long history, and the very numerous experiments which have been carried out in recent years with the aid of a fuller knowledge of asepsis, the subject of repairing large defects in bone is still very imperfectly understood.

The indications for bone transplantation or some similar procedure are:

1. To afford a protection to underlying organs, notably to the brain after extensive removal of the cranium by accident or operation.

2. To preserve the normal contour of the parts—for instance, after loss of the bridge of the nose or half of the lower jaw.

3. To maintain the continuity of a bone so that the power of a limb shall not be lost.

4. To shorten the time of recovery, for a deep cavity in a bone—for example, in the head of the tibia—heals very slowly and often imperfectly.

In considering this subject of plastic operations upon bone, it is well to remember that osseous tissue has only a slight regenerative power, while the power of the periosteum to form new bone is very great indeed. This is constantly illustrated by the repair of comminuted fractures, the injured bone being restored to something like its former condition, though many fragments may have been lost. One must therefore accept with great caution accounts of the incorporation into the structure of a bone, of bone chips or decalcified bone which surgeons have introduced into a bony gap to hasten recovery. The new bone under such circumstances may have come from periosteal flaps which were not destroyed by the accident.