ANATOMY FOR SURGEONS: VOLUME 3

The Back and Limbs

SECOND EDITION

W. Henry Hollinshead, Ph.D.

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PREFACE

This Second Edition of Volume 3 of *Anatomy for Surgeons* attempts to present, as did the First Edition, anatomical facts and concepts concerning the back and limbs that are of particular interest to the surgeon. It is not intended to be a complete descriptive anatomy of these parts, but is designed to serve both as a ready reference in which the surgeon can find general descriptions of the basic anatomy and as a review of numerous, sometimes minute, anatomical details that have proved useful to others but are not readily available without wide reading both within and outside his own special field. While no attempt has been made to describe the indications for, or detailed technic of, specific operations—for these are matters that belong to surgery and not to anatomy—particular care has been taken throughout this volume to relate the anatomical and physiologic details and concepts to underlying surgical procedures.

Most of the anatomy described in the First Edition is still both valid and pertinent. However, additions, improvements, and refinements in our understanding of anatomical details and their functional importance have contributed to, and, in turn, have been contributed to by similar additions, improvements, and refinements in diagnostic and operative procedures on the back and limbs to such an extent as to make a thorough rewriting of this book necessary. The basic descriptions have been carefully scrutinized for minor errors and reworded, re-arranged, or partly rewritten as those seemed to serve the interests of greater clarity or accuracy; discussions of material that now seems largely of historical value have been shortened or eliminated; and in all of the chapters numerous minor revisions have been made to incorporate appropriate up-to-date clinical findings and applications.

The most pervasive changes have to do with the actions of the various muscles as revealed by electromyography, concerning which very little was available at the time the First Edition was prepared. While there are still admitted gaps in our knowledge, skillful use of this technic and meticulous analysis of its results by a number of workers have added much to our understanding of the movements of all the major joints of both limbs, of the thumb and fingers, and of the vertebral column.

In Chapter 1, among the general subjects for which new findings or concepts are presented are the blood supply of bones, the lubrication of joints, repair of muscle and tendon, and the structure of nerves.

Chapter 2 contains changed or additional material on the back, including discussions of a variety of subjects in addition to the newer information on the action of the muscles. Among these are the blood supply of the vertebrae and the innervation of the vertebral column; the posterior vertebral ligaments; the intervertebral disk; movements of the vertebral column; scoliosis; and cervical spondylosis.

In Chapters 3 through 6, the upper limb, there is new material on the sternoclavicular joint; acromioclavicular dislocation; the support of the humerus; recurrent dislocation; electromyography of muscles of the shoulder, arm, and forearm; blood supply of the scaphoid; dislocation at the metacarpophalangeal joint; electromyography of the muscles of the thumb; the role of muscles and ligaments in movements of the fingers; and injuries to various nerves in the arm, forearm, and hand.

Similarly, in Chapters 7 through 9, descriptions and discussions of the lower limb that have been revised to incorporate more recent information include the structure and the blood supply of the upper end of the femur; congenital dislocation of the hip; actions of muscles at the hip, knee, and ankle; dislocation of the patella; the menisci and ligaments of the knee joint; congenital deformities of the foot; support of its arches; ligaments of the ankle and foot; fascial spaces of the foot; and superficial veins of the foot.

Well over 400 new references have been added, in an effort to make the Reference lists up-to-date guides to the literature when further details are required. As in the First Edition, priority was not a consideration in the choice of new references; nor does the necessary elimination of various older references reflect upon their quality.

The first edition of this book was completed after the Nomina Anatomica or Paris Nomina Anatomica of 1955 became available, and an anglicized version of the N.A., rather than of the older B.N.A., was therefore used. While the present volume attempts to follow the Third Edition of the N.A., published in 1966, this has involved only a few minor changes from the First Edition. As in that edition, however, I have tried to include the more commonly used synonyms at least once, and have listed them in the index when they differ appreciably from the N.A.

The figures have been reviewed, and revised and added to as seemed desirable. Most of the new figures were obtained from friends, to whom I again tender my thanks. I am grateful also to W. B. Saunders Company for allowing me to continue to use many figures from my "Functional Anatomy of the Limbs and Back" published by them. A new feature concerning the figures is the index listing of the pages on which the more important structures are illustrated.

I am, as before, much indebted to my Surgical Consultants, listed on the preceding pages. They have, among them, read and criticized for me the entire volume, and I have drawn freely on their knowledge and experience. I am also particularly indebted to the Section of Medical Illustrations, under the direction of Mr. Vincent Destro; to Dr. Carl Gambill, of the Section of Publications; and to my secretary, Miss Esther Peters. To these, and to my publishers for their cooperation, my thanks.

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CONTENTS

CHAPTER 1

Some General Considerations

SINCE this volume deals largely with bones, muscles, nerves, and blood vessels, and there are a number of general facts and principles that are equally applicable to these structures in whatever region they occur, it seems appropriate to consider some of these.

BONE, CARTILAGE, AND JOINTS

BONE

Bone regularly occurs in two forms, compact and spongy (cancellous). Compact bone forms the surface of all bones, and the major part of the body or shaft of long bones; spongy bone occupies the ends of long bones, and permeates the bodies of the short and flat bones. The large medullary cavity in the body of a typical long bone is, in the adult, occupied by yellow marrow. The much subdivided medullary cavity in spongy bone is occupied by red marrow, which produces the granular leukocytes and the red blood cells.

Compact or cortical bone contains the Haversian canals, longitudinally running channels for the accommodation of blood vessels, about which the bone is laid down in concentric lamellae that are now usually called osteons or osteones; spongy bone also consists of lamellae, but these are in flat branching plates rather than concentric circles.

The articular surfaces at synovial joints are covered, outside the thin plate of cortical bone, by hyaline cartilage, except in a very few joints, such as the sternoclavicular and the temporomandibular, where fibrocartilage is present instead. The remainder of the bone is covered externally by the periosteum, a layer of specialized connective tissue that is firmly bound to the bone by some of its fibers, which enter the bone as Sharpey's fibers, and contains blood vessels that connect with those in the bone. The outer layer of the periosteum is denser, and contains the periosteal blood vessels, while the inner layer is looser and contains in adults the fibroblasts which can, under the proper conditions, proliferate and form osteoblasts for the reconstruction of cortical bone. The endosteum is a thinner layer of connective tissue lining the bone where it abuts on the marrow cavity; it also contains cells which are capable of forming bone.

TRABECULAR STRUCTURE AND MECHANICS

The structure and the mechanical properties of bone have been the subject of numerous investigations. "Wolff's law" states essentially that every bone is constructed in such a fashion as to allow it to resist the forces applied to it, so that if the direction of the forces change, there will be a corre-

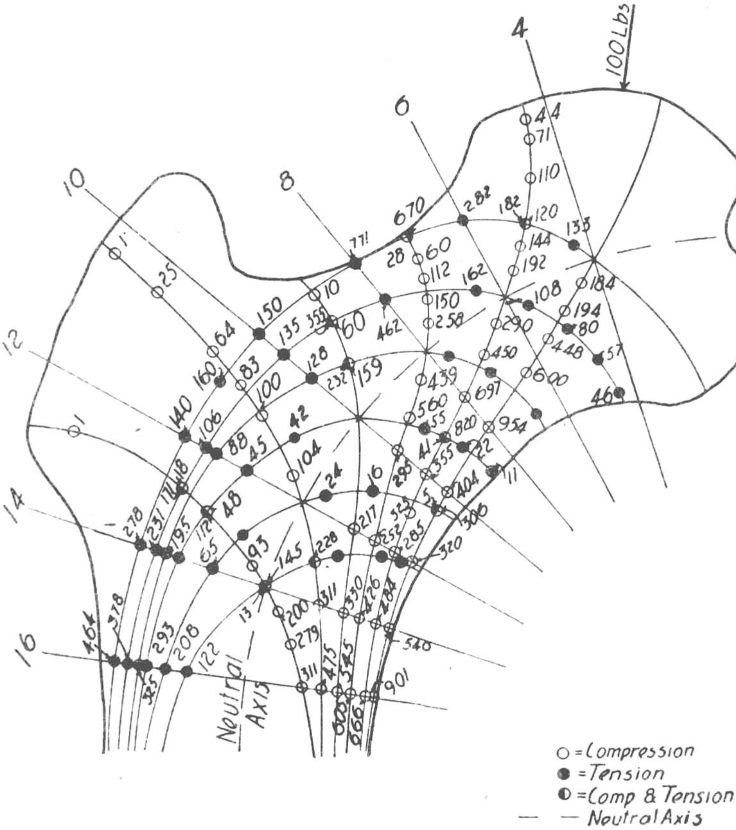

Fig. 1-1. Koch's calculations of the maximal tensile and compressive stresses in the upper end of the femur when there is a load of 100 pounds on the femoral head. The numbered lines extending across the femur represent the levels of the cross sections that he studied for the bony architecture. (From original of Fig. 19*a*, Koch, J. C.: *Am. J. Anat. 21*:177, 1917.)

sponding change in the structure of the bone. Koch's analysis of the compressive and tensile stresses in the femur, by mathematical means, led him to conclude that this rather complex bone accords strictly in structure to the best engineering principles—maximal strength with a minimal use of material. Comparing the calculated lines of tension and compression in the head and neck of the femur (Fig. 1-1) with the actual arrangement of the trabeculae here (Fig. 1-2), he apparently showed that the trabeculae are arranged in exactly the pattern demanded by his mathematical analysis.

In general, the trabeculae arising from the lateral side of the femur and arching medially correspond to the calculated tensile stresses—that is, the internal force in the bone that tends to keep two adjacent planes from being pulled apart—while the trabeculae arising from the medial side of the femur and arching upward and laterally correspond to the lines of compressive stress—that is, resist the compressive forces brought about by a load on the head of the femur. Similarly, Koch showed that the absence of trabeculae in most of the body is also according to mathematical and engineering principles (for the stresses borne by this part are most economically cared for by a tube such as is offered by the cortical bone here), and that the trabeculae in the lower part of the femur are arranged in accordance with the stresses here.

Fig. 1-2. A thin frontal section of the femur to show the trabecular structure. Note the correspondence between the trabeculae here and the lines of tension and compression in Figure 1-1. (From original of Fig. 21, Koch, J. C.: *Am. J. Anat. 21*:177, 1917.)

The principles enunciated by Koch are now generally accepted and explain the alteration in structure when there are abnormal stresses, such as those present when there is a valgus or varus deformity of the femur (for instance, Tobin). They are also in accord with the observed deformation and fracture of bone under conditions of loading, as reported especially by Evans and his coworkers in numerous papers (see Evans, '57).

The physical properties of bone vary somewhat. Koch quoted the tensile strength—the resistance to being pulled apart—of bone along its long axis as varying from about 13,200 to about 17,700 pounds per square inch, its compressive strength—resistance to being crumbled—along its long axis as varying from about 18,000 to 24,700 pounds per square inch. These figures can be compared with a tensile strength of 65,000 pounds per square inch, a compressive one of 60,000, for medium steel; a tensile strength of 28,000 pounds, a compressive one of 42,000, for copper; a tensile strength of 1,500 pounds, a compressive one of 15,000, for granite; and a tensile strength of 12,500 pounds, a compressive one of 7,000, for white oak when the load parallels the grain, but both tensile and compressive strengths of only about 2,000 pounds per square inch when the load is at right angles to the grain. Koch pointed out that the tensile strength of bone is regularly less than its compressive strength, a finding substantiated by the observation (Evans) that fractures of the femur regularly originate on the convexity of a femur distorted by a load or a blow and therefore represent a failure under tensile, not compressive, strain.

Evans and Lebow restudied, by engineering technics, the tensile strength of bone as a whole, and found that it varies not only from bone to bone but within different parts of the same bone. Thus the middle third of the femur was found to have a greater tensile strength than the proximal and distal thirds, and the middle third of the tibia had a greater tensile strength than did the middle third of the femur. The tensile strength of wet specimens, more nearly approximating living bone, was found to be considerably less than that of dried specimens, concerning which figures are usually quoted; the average tensile strength of the middle third of wet specimens of the femur was only a little more than 12,000 pounds per square inch, while that of dried specimens exceeded 16,000 pounds. In contrast, however, wet specimens elongated under tension much farther than did dried bone—that is, were able to absorb a greater amount of energy. Ascenzi and Bonucci found these differences to hold also for individual osteons and added that the tensile strength varied according to the arrangement of the collagen fibers in successive laminae of an osteon, being greatest when a longitudinal direction of the fibers predominates. Evans and Bang reported that the osteons apparently contribute most to hardness of the bone, the interstitial lamellae most to tensile strength. Weaver and Chalmers reported that the compressive strength of the trabeculae of cancellous bone bears a constant relationship to the mineral content, and that both apparently increase to approximately the age of 30; they also reported suggestive evidence that both may increase in response to stress.

CONSTITUENTS

Cortical bone contains about 25 to 30 per cent of water (Evans and Lebow). Of the dry weight about 60 to 70 per cent is mineral, apparently tiny crystals of $Ca_{10}(PO_4)_6(OH)_2$ (an hydroxyapatite) with carbonate and citrate bound to their surfaces (McLean and Urist), while the fibrous connective tissue, collagen or ossein (ostein), constitutes about 30 to 40 per cent of the interstitial substance. In contrast to the usual statement that the relative amount of collagen is greatest in young individuals and decreases with age, thus accounting for the occurrence of "greenstick" fractures in the young and increasing brittleness in the elderly, Mueller and co-workers found the organic fraction remaining constant; they said the change is in water content and mineralization, the latter increasing as the former decreases from birth to the sixth or seventh decade. The loss of calcium salts as in rickets and osteomalacia is, of course, of great importance clinically. In osteoporosis the mineral content is normal, but the amount of bony tissue is reduced (Mueller and co-workers), apparently as a result of increased resorption of bone (Jowsey and co-workers). There is also apparently a normal diminution of cortical bone with age, for while the sizes of the osteons remain constant, the sizes of the Haversian canals increase in the cortex of the femur, and the cortex of the ribs decreases in thickness (Jowsey).

The collagenous fibers of the osteon surrounding a Haversian canal vary from an almost longitudinal to an almost circular arrangement around the canal, and in many osteons the direction of the fibers alternate from one lamella to the next (see, for instance, Cooper and co-workers). This type of osteon, however, has less tensile strength than when the majority of fibers are longitudinally arranged (Ascenzi and Bonucci). The alternating arrangement, from essentially longitudinal to essentially circular, tends to be true also of the lamellae forming the external surface of cortical bone (Smith, '60).

BLOOD AND NERVE SUPPLY

The *blood supply* to bones varies according to the shape of the bone. In long bones, however, there are generally three sets of vessels: one or more nutrient arteries, accompanied by paired veins; periosteal vessels; and metaphyseal and epiphyseal vessels that penetrate the ends of the bones. The nutrient artery of most long bones is of somewhat variable origin when there are two or more associated vessels that might give rise to it, and may be multiple instead of single. Thus the concept that "the" nutrient artery is necessarily the first vessel to invade the cartilage matrix of the forming bone, and hence that the line of intersection of the nutrient canal with the center of the bone marrow indicates the original center of the bone, from which the amount of growth at either end can be calculated, is not now generally adhered to (for instance, Hendryson).

The nutrient artery or arteries, with their accompanying veins, usually penetrate the cortex obliquely (their direction, whether distal or proximal, indicating the end at which the lesser growth in length of the bone has occurred) and branch to run toward both ends of the bone; they supply the greater part of the marrow, and they anastomose with the metaphyseal arteries at the ends of the bones. The blood flow to the cortex is then derived from the medullary vessels (see, for instance, Nelson and co-workers, Brookes and co-workers) through radially directed branches that enter the cortex and quickly divide into small vessels that run in the Haversian canals. Most of the vessels in the Haversian canals are capillaries or venules, although an occasional canal contains an arteriole; venous drainage from the ends of a long bone is largely into veins accompanying the epiphyseal and metaphyseal arteries, but that from the body of the bone is mostly toward the medullary sinusoids (Nelson and co-workers).

It has long been known that the cortical vessels are connected to periosteal vessels, and various experiments have shown that the periosteal vessels can supply cortical bone. Nelson and co-workers found no arteries entering the cortex from the periosteum, however, and Brookes and co-workers, also noting that connections to periosteal vessels are capillary ones, emphasized that blood flow is normally from the cortex to the periosteum (and also into the muscles attached to the bone) and that reverse flow occurs only when there is ischemia of the bone. Even in the fetus the communication between the cortical and periosteal vessels is through capillaries (Brookes).

The possible importance of the periosteal blood vessels is indicated by the reports that interruption of the main nutrient vessels to the femur of rabbits produces primarily necrosis of the central portion of the marrow (Huggins and Wiege), while if the periosteum is also stripped from most of the femur at the same time, infarction of the entire thickness of the femur throughout about its middle third ensues (Foster, Kelly, and Watts). Thus, the vessels entering the ends of the bones are apparently not capable, without the aid of the reversed flow from the periosteum, of supporting the entire cortex.

In growing long bones, where the metaphyseal and epiphyseal arteries are separated by the epiphyseal cartilage, it is apparently the epiphyseal vessels that are responsible for growth of the epiphyseal cartilage, but it is the metaphyseal ones that are responsible for the transformation of the cartilage into bone (Kistler; Trueta and Amato).

Lymphatics are present in the periosteum, and have been said also to accompany blood vessels into the bone, but little seems to be known about them.

Nerve fibers also have been traced into bone, along the blood vessels. Kuntz and Richins traced nerve fibers into the bone marrow, and found that for the most part they remain related to the blood vessels; through degeneration experiments, they showed that some of them were afferent and some were sympathetic. Miller and Kasahara found fibers ending in association with arterioles, the endosteum, and the deep surface of the articular cartilage, but could not confirm reports that nerve fibers extend also into the lamellae of cortical bone.

The concept that there may be nerve fibers in the bone which have a trophic function, in some way governing the growth and repair of bone, is apparently negated by the experiments of Corbin and Hinsey; they destroyed the sympathetic and afferent innervation to one hind limb of a number of cats, and compared the denervated and normally innervated bones and joints at periods ranging from 2 weeks to 3½ years. In the animals whose movements were restricted, no changes at all were found; in those that were allowed to run freely in large cages there was trauma of the anesthetic hip joint, but there were no other changes except those attributable to this trauma. Ring later agreed that sympathectomy has no effect, but reported that denervating the muscles of the leg produced at least a temporary increase in the growth of the length of the tibia. This has, of course, nothing to do with the innervation of bone; Ring reported that tenotomy of all the muscles of the leg has the same effect.

Growth and Repair

With the possible exception of the clavicle, the ossification of which is peculiar, all the bones of the limbs and vertebral column are preformed in cartilage. Erosion of cartilage through the ingrowth of blood vessels tends to occur at about the middle of the cartilaginous mass, and bone laid down where the cartilage has been eroded establishes the first center of ossification. In the case of long bones (Fig. 1-3) the first center of ossification is for the body or shaft (diaphysis); for the various vertebrae, three primary centers appear approximately simultaneously, one (or two uniting quickly into one) for the body and two for the arch. Centers of ossification grow by a continuation of the process through which they arose, erosion of cartilage and replacement by bone; as the bony center for the body of a long bone spreads it soon comes to replace the entire cartilaginous thickness of the body and thereafter growth in diameter of the bone can occur only through the activity of the osteoblasts associated with the periosteum.

CENTERS OF OSSIFICATION

Each carpal bone normally ossifies entirely from a single center; so does each tarsal, except for the calcaneus, which normally develops an epiphysis at its posterior end. In the vertebrae, epiphyseal centers appear at the tips of the spinous and transverse processes. The larger long bones develop two epiphyseal centers of ossification (Fig. 1-3), one in each cartilaginous end of the developing bone. The shorter long bones —the metacarpals and metatarsals, and the phalanges of both the hand and foot— typically develop only single epiphyseal centers, which are in the distal ends of the second to fifth metacarpals and metatarsals, in the proximal ends of the first metacarpal and the first metatarsal, and in the proximal ends of all phalanges. Finally, additional epiphyseal centers appear in the cartilage of the ends of some long bones—for instance, centers for the several parts of the distal end of the humerus. As the epiphyseal centers expand, most of the cartilage at the ends of a long bone is also replaced, but a thin layer of cartilage remains over the articular surface of the end of the bone, and a plate of cartilage, the epiphyseal cartilage or epiphyseal plate, persists for a time—it may be years—between the ossified epiphysis and the ossified shaft.

The details of ossification of the various bones are best considered in connection with the regions in which they occur. In general, however, centers for ossification of the long bones appear during the seventh and eighth weeks of fetal life (that of the clavicle, the first to appear, is usually said to be recognizable at 5 weeks), and so do the primary centers for the vertebrae except for the coccygeal ones; by the time of birth the

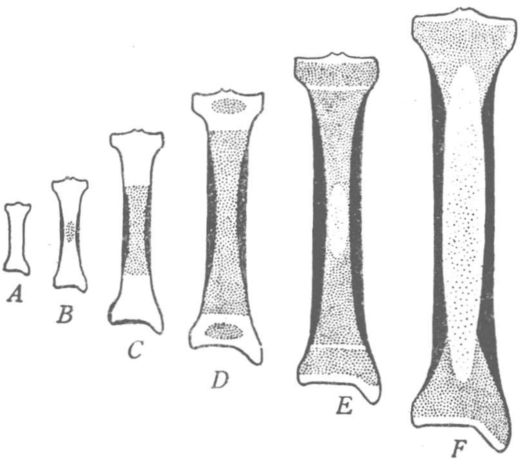

Fig. 1-3. Schema of the ossification and growth of a long bone. White represents cartilage; stipple, spongy (endochondral) bone; black, compact (perichondral) bone. **A** is the cartilaginous stage; in **B** and **C** both endochondral and perichondral bone appear and increase; in **D** the epiphyseal centers have appeared, in **E** the epiphyses have reached their full growth, and in **F** they have joined the body. In the last two stages the marrow cavity (light stipple) appears and spreads through resorption of spongy bone. (From Arey, L. B.: *Developmental Anatomy* [ed. 6]. Philadelphia, Saunders, 1954.)

major part of each long bone, the body, is completely ossified. In contrast, the single center of ossification for most of the carpals and tarsals appears only shortly before or, more commonly, after birth, and so do the centers of ossification for the epiphyses, and for the coccygeal segments of the vertebral column; these parts, then, are entirely cartilaginous at birth or have only a small nucleus of ossification in the relatively large cartilaginous mass.

The dates of appearance of the centers of ossification of the carpals and tarsals vary markedly with the bone: for instance, a center is recognizable in the calcaneus at about the sixth month of prenatal life, and centers for all the tarsals appear during approximately the first 4 years of postnatal life, while those for some of the carpals may appear slightly later—that of the pisiform, an extreme, being usually not visible until the ninth or tenth year in females or the thirteenth to fourteenth year in males (Paterson). Similarly, the dates of first appearance of the epiphyseal centers vary even more markedly according to which one is being considered: centers for the head of the humerus, the lower end of the femur, and the upper end of the tibia are either present at birth or appear shortly thereafter; the epiphyseal center of the olecranon does not appear until about the age of 11; and the epiphyses of the vertebrae typically appear between the ages of 15 and 20.

According to Hill the appearance of ossification centers from about the second month of prenatal life onward is rather accurately correlated with the age of a healthy fetus, sufficiently so that the age can be calculated from the appearance of the centers. Hill; Noback and Robertson; Francis and his coworkers ('39, '40); Flecker ('32, '42); Davies and Parsons; Paterson; and others, have provided extensive data upon the time of appearance of the various centers of ossification, and the time of fusion of epiphyseal centers with the body. Pryor ('36a and b) emphasized the bilateral symmetry of ossification in infants and children, and the fact that identical twins and triplets show similar small anomalies in ossification (of the hands), while there are no more similarities between nonidentical twins than between parents and children.

Pryor ('28) stressed the fact that the carpal bones ossify in the female sooner than they do in the male, and that earlier ossification in general is typical of the female child; Paterson found earlier ossification, not only in regard to the carpals and tarsals but also in regard to the dates of appearance of all the epiphyses and the dates of their union to the body, to be typical of the female. Hill noted that even during the last 3 months of prenatal life the female, as judged by the centers of ossification, matures somewhat more rapidly than does the male. In general, however, the earlier a center of ossification appears, the less likely is there to be any difference between its time of appearance in the male and the female, while the later it appears, the greater the gap between the two sexes in the time of appearance. In postnatal life, not only are the dates of appearance of the epiphyses in the female up to 6 months earlier than those of similar epiphyses in the male, but fusion of the epiphyses also typically occurs earlier in the female than in the male; the difference is usually a year or more, and in the case of certain epiphyses may be as much as 5 years (Paterson). As a general rule, the earlier a center of ossification appears in one of the two epipyhses of a long bone, the later this epiphysis is united to the body.

GROWTH

Once the body of a long bone is ossified, as it generally is long before birth, growth in diameter of the bone necessarily involves an entirely different method, for there is no further peripheral cartilage to be replaced. Therefore, growth in diameter of a long bone is primarily periosteal, with successive layers of bone being laid down on the periphery by the periosteum, while the inner layers of bone, adjacent to the medullary cavity, are being constantly resorbed in order to enlarge the medullary cavity, and reorganized into Haversian systems or osteons around the blood vessels. According to LeBlond, Wilkinson, Bélanger, and Robichon, in later stages of growth the endosteum also contributes to bone formation in the shaft near the epiphyses, this contribution accounting for the widening of the cortex and the narrowing of the marrow cavity at these levels. Epker and Frost, taking advantage of the fact that tetracycline is deposited in newly formed bone, reported that periosteal growth may occur also at almost any age beyond the growth period.

In contrast, increase in length of the body is endochondral, as was the original development of the bone, for each epiphyseal plate goes through a constant cycle of proliferation, calcification, and absorption of cartilage, with replacement by bone, on the side adjacent to the body. Trueta and Little suggested that one factor in calcification is a too great separation of the deep layers of the plate from the nourishing epiphyseal vessels.

It has long been known that one end of any long bone with two epiphyses grows much greater in length than does the other one, and this apparently accounts for the obliquity of the nutrient canal, which almost always points toward the slower growing end (unexplained are occasional cases, quoted by Mysorekar as occurring in about 1 per cent of femurs and found by him in 5 per cent of fibulas, in which the canal points toward the faster growing end); similarly, where only one epiphysis exists, as in the metacarpals, the nutrient canal is slanted away from this epiphysis. Among the large long bones of the limbs, the humerus grows more at its proximal end, and so do the tibia and the fibula, while the radius, the ulna, and the femur grow more at their distal ends.

Payton ('32) emphasized that the greater growth at one end of a long bone is not merely a function of time, but depends primarily upon a faster rate of growth at this end. In experiments on pigs, he found that there is, in general, a gradual decrease in the rate of growth of every bone as the animal becomes older, but that, while the rate as a whole decreases, the decrease in rate is less at the faster growing end than at the slower one—in young pigs, the faster growing end grows about twice as fast as the slower growing one, while in older pigs it grows about three times as fast.

Growth in diameter of an epiphysis is periosteal, as is that of the body, and growth in length of the epiphysis is endochondral, as is that of the body. (Similarly, growth in diameter of the epiphyseal and articular cartilage seems to be by apposition from the perichondrium—Soloman.) It is now fully accepted, as demonstrated especially by Payton ('32, '33) by feeding madder to pigs, that all new bone formation from the epiphyseal cartilage adds only to the length of the body, and that it is growth and replacement of the articular cartilage only that adds to the length of the epiphysis. (Why the articular cartilage, unlike the epiphyseal one, is not finally replaced entirely by bone is not known. McKibbin and Holdsworth, '67, reported an interesting experiment in which they reversed a piece of articular cartilage, placing its articular surface against endochondral bone; it continued to grow, but there was no ossification at this surface.)

Payton found that the epiphysis at the most rapidly growing end of the bone also grows most rapidly, but there is no correlation between the total length an epiphysis attains and the rapidity of its growth. Further, the epiphysis does not lengthen as rapidly as would be expected, for while bone is being added by the articular cartilage, absorption of bone simultaneously occurs at the junction of the bony epiphysis with the epiphyseal cartilage. Thus two epiphyses with approximately the same rate of growth may attain different lengths—some epiphyses (of the pig) may increase in length only 1 to 3 mm. in more than 500 days, while others, growing at about the same rate, increase 13 mm. or more in length.

It has, of course, long been known that hormones, especially those of the anterior lobe of the hypophysis (pituitary gland), of the thyroid gland, and of the gonads strongly influence the growth and maturity of the skeletal system. Without an attempt being made to analyze these effects in any detail, they can be summarized by the reminder that both the growth hormone of the anterior lobe of the hypophysis and thyroxin are necessary for proper skeletal growth, and that lack of either of these hormones inhibits growth.

As studied in the guinea pig, the exact response of cartilage and bone to hormones varies somewhat with the age of the animal (Silberberg and Silberberg, '40). According to Ray, Evans, and Becks, growth hormones injected into an otherwise normal animal not only increase the rate of growth of the cartilage, but also increase the rate of osteogenesis; however, pituitary growth hormone injected into animals that have been thyroidectomized and parathyroidectomized in the first few days of life acts differently, for Ray, Simpson, Li, Asling, and Evans reported that under these conditions the growth hormone causes marked increases in the dimensions of the skeleton without evidence of further skeletal maturation. Thyroxin stimulates ossification (Silberberg and Silberberg; Ray, Simpson, and their co-workers), and the effects of maturation of the skeleton produced by the anterior lobe of the hypophysis are therefore apparently brought about through the influence of this lobe on the thyroid gland. The optimal balance between dimensional growth and maturation of the skeleton is therefore normally brought about through proper balance between the activity of the anterior lobe of the hypophysis and the thyroid gland.

Sex hormones, in contrast, promote changes in the epiphyseal cartilages. Estrogen, for instance, inhibits the differentiation of epiphyseal cartilage (Silberberg and Silberberg, '41); the earlier union of epiphyses in the female thus seems to be a consequence of the earlier sexual maturity of the female. Similarly, it is well established clinically that delayed epiphyseal union is a common consequence of dysplasia of the gonads, and that early fusion of the epiphyses is associated with sexual precocity.

Histochemical aspects of the development of bone have been studied by, among others, Bevelander and Johnson, and Heller-Steinberg; of significance in the development of bone is the finding of McLean and Bloom and of Bloom and Bloom that under optimal conditions during both early development and later growth bone matrix is calcified as it is laid down, and thus there is no osteoid —that is, uncalcified bone matrix—under ideal physiological conditions. They related the appearance of osteoid to a failure in the local supply of the proper minerals.

ATTEMPTS TO ALTER BONE GROWTH

Disparity in the rate of growth of the limbs, leading to an ultimate discrepancy in lengths, is particularly crippling when it oc-