Frazer's

ANATOMY OF THE HUMAN SKELETON

FIFTH EDITION

Edited by

A. S. BREATHNACH

M.D., M.Sc.

Senior Lecturer in Anatomy
St. Mary's Hospital Medical School
London

With 197 Illustrations

Many in Colour

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PREFACE TO THE FIFTH EDITION

THE point of view from which the anatomy of the skeleton is approached in this book is outlined in the late Professor Frazer's preface to the first edition, which is reproduced on the following page. In the present edition, both the manner of approach and the detail necessary for its proper fulfillment have been preserved. The changes that have been made are concerned largely with bringing the book up to date in certain sections, and with a re-arrangement of others which it is hoped will make for easier reference to particular items. This has been further facilitated by the provision of more sub-headings.

The first chapter has been almost completely re-written and expanded to include reference to recent work on the development, growth, and ossification of bone. In Chapter II, some alterations have been made to the sections dealing with the intervertebral discs, the movements, and the development and ossification of the vertebral column. In Chapter III, the account of the development and ossification of ribs and sternum has been brought up to date. Chapters IV and V of the previous edition, dealing with the limbs, have each been sub-divided, and new material relating to, for instance, the movements of the shoulder girdle, and the semilunar cartilages of the knee has been introduced. The sections on the pelvis and the arches of the foot have been largely re-written. The skull is now dealt with in two separate chapters, and as far as possible all matter relating to the skull as a whole has been brought together in the first of these. The sections dealing with the development and growth of the skull and craniometry, have been almost entirely re-written, and the paranasal sinuses have been given somewhat fuller treatment. In addition, other minor alterations have been made here and there throughout the book. A new index has been prepared.

Certain illustrations appearing in the previous edition have been deleted, nine have been re-drawn, and the legends of a number have been shortened. For the first time a number of X-rays have been included, for which, with the exception of those in Plate 8, I am indebted to Dr. E. Rohan Williams, Director of the Radiology Department, St. Mary's Hospital. I am grateful to the publishers for allowing me to include these, and for their kindness and co-operation in all matters relating to the preparation of this edition.

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PREFACE TO THE FIRST EDITION

It is not necessary to lay emphasis on the importance of a knowledge of the skeleton as an integral part of the study of human anatomy, and, in the literature bearing upon the subject, we find masterly accounts of the constituent bones which rank as classics in the education of the student. In this book I have ventured to wander in some degree from the well-trodden road and to lead the reader by other ways to the comprehension of his subject. My intention has been to induce him to think of the bones as they exist in the body rather than as they lie on the table before him, and to do this I have laid stress—because he must use the prepared specimens—on the meaning of small details and on the relations of the bone, and have relegated the pure description of the dry bone to a secondary place: in other words, each part of the skeleton has been used as a peg on which to hang a consideration of the neighbouring structures, in the hope that this may afford a new point of view to the reader and enable him to grasp the intimate connection between them.

Such a way of regarding the skeleton opens up a very extensive field of description, and within the limits of a student's hand-book it is only possible to deal with some out of the many points which offer themselves for development, but I hope that those of which I have treated in this volume may be of value to the student and may lead him to think of the skeleton as something more than a dry subject for study, and to search for reasons for the hundred and one abstract and concrete qualities which his own observation will prove any particular bone to possess. If it has this effect, one of my objects in writing the book will have been attained.

The majority of the illustrations, which the generosity of Messrs. J. & A. Churchill has enabled me to insert, are intended merely to help the student to apply the descriptions in the text to the actual specimens: if, in spite of their many artistic imperfections, they are of use in this respect, I shall be content. They have been drawn from specimens in my possession or in the Anatomical Department in the School of this Hospital.

It is a pleasure to acknowledge my indebtedness to my colleague, Dr. R. H. Robbins for his careful reading of the proofs, to Mr. R. M. Handfield-Jones for the same service in a part of the work, and to my wife for help in preparing the book for the press.

J. ERNEST FRAZER.

Medical School,
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CHAPTER I

INTRODUCTION

The *skeleton* constitutes the framework on which the soft tissues of the body are supported. In addition, it affords a number of strong systems of levers by means of which the muscles may alter the position of the body as a whole or of its various parts. During life, the individual bones of the skeleton are connected to one another by means of *cartilages* and *ligaments* to form articulations, or *joints*. Here, movement may occur, the range and direction of which is dependent upon the form and degree of congruity of the articular surfaces of the bones, as well as upon the nature of the ties which unite them.

Bones may be described according to their shape and appearance as being *long*, *short*, *flat*, or *irregular*, and those of the trunk and skull together constitute the *axial skeleton*, as distinct from the *appendicular skeleton* of the limbs.

STRUCTURE OF CARTILAGE AND BONE

Cartilage is a dense connective tissue which is tough but elastic, and compressible to a considerable extent. It consists of a gel-like matrix permeated by a network of collagenous fibres, and containing groups of cartilage cells or *chondrocytes*. The matrix is the pressure resisting component of cartilage, and the collagen fibres are responsible for its tensile properties. Histologically, three types of cartilage may be distinguished. In *hyaline* cartilage, the fibres are very fine, and can only be demonstrated by means of special techniques; in *elastic* cartilage the matrix contains large numbers of elastic fibres, and *fibro-cartilage* consists of a dense meshwork of collagenous fibres with relatively few cartilage cells scattered between the bundles. Hyaline cartilage tends to be changed into fibro-cartilage as age advances, or it may undergo calcification.

Cartilage is usually described as being avascular, and the chondrocytes are thought to be nourished by diffusion of fluid and crystalloids through the matrix. However, blood vessels have been found to occur in cartilage in certain situations. Peacock (1952) found small blood vessels in the adult intervertebral disc, and Haines (1933) has drawn attention to the wide occurrence of vascular canals in human fœtal cartilage, and in the epiphyseal cartilages of the long bones in the child. The vessels contained in these canals provide blood for the active process of ossification when this commences in the depth of the cartilage.

In the adult skeleton cartilage is found completing the skeleton of the thorax (*costal cartilages*), holding bones firmly together, as in the vertebral column, or filling up intervals between bones as in certain parts of the skull. *Articular cartilage* coats the articular surfaces of bones and receives and transmits any forces which may be acting across the joint. It is usually described as being of the simple hyaline variety, but MacConaill (1951) believes it to be largely composed of collagen fibres. *Intra-articular cartilages*, or menisci, are partial or complete plates of fibro-cartilage interposed between the articular surfaces of certain joints where a particular combination of movements occurs; further consideration will be given to these in the section dealing with the knee-joint (page 134).

Bone

Bone is extremely hard, but at the same time exhibits a small amount of elasticity and toughness. It can be looked upon as composed of animal or organic matter impregnated with inorganic salts; analysis gives roughly about one-third or less of organic matter, and the rest as mineral matter, mainly calcium phosphate. The organic matter gives toughness, and the inorganic matter hardness, to the composite result.

The surface of fresh bone has a pinkish hue, and is covered by a fibrous *periosteum* of variable thickness. Bone exists in two states, termed according to the appearance it presents, *compact* or *cancellous*. Compact bone is dense and very hard, while cancellous bone has an open trabecular arrangement. The shaft of a long limb bone (Fig. 1) consists of an outer shell of compact bone within which is contained the hollow *medullary cavity*. At each end of the bone the cavity is occupied by cancellous tissue. The medullary cavity and the interstices of the cancellous bone are filled with vascular *marrow* of which two distinct varieties are found. *Yellow marrow* is found in the shafts of long bones, and *red marrow* in their articular ends, as well as in the cancellous tissue of vertebræ, ribs, sternum, skull, and pelvis. Red marrow is hæmopoietic in function, and is present throughout all the bones at birth and for some time after. From the age of 7 or 8 onwards it is gradually replaced by yellow marrow in the shafts of long bones, and later in life, in the spongy tissue as well.

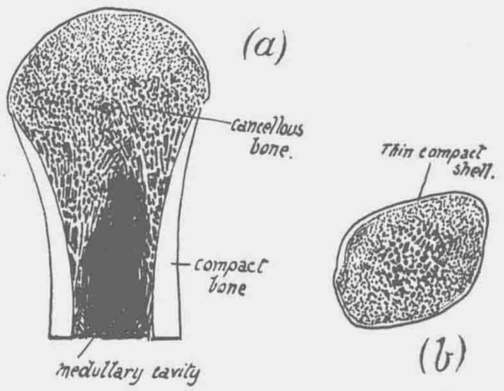

Fig. 1. Diagram of a section of an end of a long bone (*a*) and a short bone (*b*) to show the arrangement of cancellous and compact tissue in them.

Microscopic Structure of Bone. Bone consists of calcified collagenous tissue the intimate structure of which is basically lamellar. In compact bone (Fig. 2) the lamellæ are arranged circumferentially in the sub-periosteal region and in the area adjoining the marrow cavity, and in concentric rings around the *Haversian canals* in the rest of the bone. These canals are

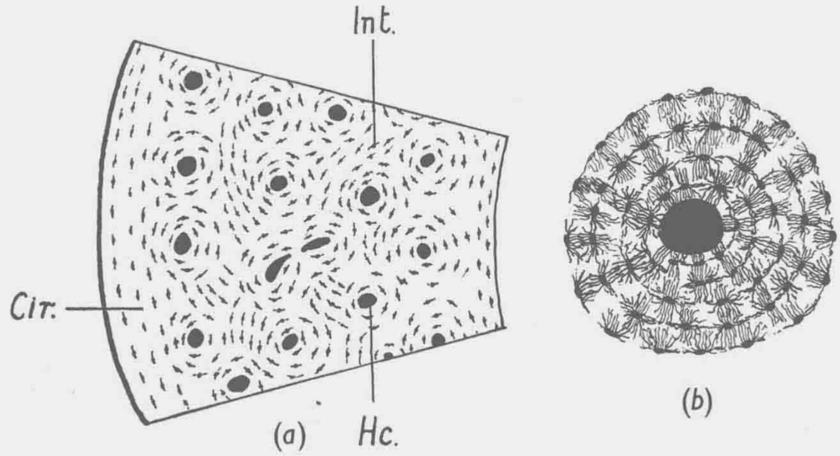

Fig. 2. (*a*) Diagram of a section of bone under a low power. *Cir.*, outer circumferential lamellæ. *Hc.*, Haversian canal. *Int.*, interstitial lamella. (*b*) Cross-section of an individual Haversian system under a higher power, to show osteocytes and their processes.

longitudinally-running vascular channels which form an anastomosing system in communication with the marrow cavity, and with the surface of the bone through *Volkmann's canals*, along which their blood-vessels run in from the periosteum. Each canal and its surrounding lamellæ forms a bony cylinder in the long axis of the bone, which is termed an *Haversian system*. The intervals between adjacent systems are occupied by irregular *interstitial lamellæ*.

The bone cells or *osteocytes* lie in spaces (*lacunæ*) between the lamellæ. The lacunæ are in communication with one another and with the central Haversian canal by means of fine canaliculi which traverse the lamellæ at right angles to the long axis of the system. Each canaliculus is occupied by a fine process given off by an osteocyte, and the processes of adjacent osteocytes are in direct protoplasmic continuity with one another. The osteocytes are *osteoblasts* "trapped" by the bone they have laid down.

The fine structure of the trabeculæ of cancellous bone is essentially similar to that of compact bone. Lamellation however, is extremely irregular, except in the larger trabeculæ.

Blood Supply of Bone. This is obtained from the arteries in the neighbourhood of the bone. They contribute to a periosteal plexus from which fine branches enter the bone through Volkmann's canals. One or two of the larger vessels entering the shaft of a long bone make what are termed the *nutrient foramina*. These larger vessels are mainly distributed to the marrow of the medullary cavity. Towards the end of the bone further numerous small foramina may be seen. These admit vessels which arise from the vascular plexus (*circulus vasculosus*) in the region of the joint. In the adult, these vessels communicate freely with those of the shaft, but in the growing bone there is little or no connection between the two while the epiphyseal plate of cartilage is still present.

Interruption of the blood supply of bone leads to death, or *necrosis* of the portion affected; stripping of the periosteum or fracture are the commonest causes.

In long bones, the nutrient foramen is directed away from the growing end of the bone. Originally it entered the bone at right angles, but as this increases in length the point of entry is carried progressively further away from the growing end, and the vessel finally comes to enter the bone in an oblique direction.

There appears to be considerable doubt as to the presence of lymphatics in bone, but nerve fibres have been shown to accompany the blood-vessels.

OSSIFICATION AND GROWTH OF BONE

Bones do not take shape as such *ab initio*, but are developed in the embryo from condensations of mesenchyme which are pre-determined towards skeletal formation from a very early date. Numerous tissue-culture experiments (see Murray, 1936; Fell, 1956) have shown that such condensations have an inherent capacity for self-differentiation into cartilage and bone of recognisable anatomical form, which is to a considerable extent independent of the influence of extrinsic factors such as muscle pull, etc. Thus, if the mesenchymal rudiment of a limb bone such as the femur is removed and grown in tissue-culture, a structure which bears a close resemblance in shape and form to the normal femur will result.

Ossification

The mesenchymal rudiment of a bone once formed, may undergo direct ossification, or it may be replaced by a cartilaginous model which in turn becomes ossified. In the former case the bone is said to be ossified *in membrane*, and in the latter to be ossified *in cartilage*. These terms simply mean that the bones have replaced cartilage or non-cartilaginous "membrane" as the case may be. The process of ossification is essentially similar in both instances, and in cartilaginous ossification the cartilage is calcified first, then absorbed, and replaced by true bony formation. The final histological structure of cartilage and membrane bone is identical. The greater part of the skeleton including that of the limbs (except for the clavicle), trunk, and base of the skull is composed of bones ossified in cartilage. The bones of the face and vault of the skull are formed in membrane. Some bones, *e.g.*, the occipital bone, are ossified partly in cartilage and partly in membrane and the two parts represent distinct morphological elements which unite to form a composite bone in the adult. Membrane bones are usually considered to represent *dermal bones*—structures formed originally as parts of an exoskeleton which in the course of evolution have sunk to a deeper position.

In the case of certain bones, *e.g.*, the mandible, where the primary ossification commences in membrane, and where there is no pre-formed cartilaginous model, cartilage subsequently appears at various sites, proliferates, and undergoes ossification. This is known as *secondary cartilage*, and its histological structure is somewhat different from that of ordinary hyaline cartilage. Its occurrence at a particular site is apparently associated with a need for rapid growth.

Ossification in Membrane. The site of ossification is indicated by a concentration of large cells called *osteoblasts* together with bundles of collagenous fibres. Through the activity of the osteoblasts calcium salts are deposited in the matrix, and this cements the fibres together. In this manner fine spicules of bone are laid down. The addition of new bone to these results in the formation of a system of trabeculæ usually arranged in a radial fashion, and the whole process extends outwards from the centre. At first the fibre bundles of the bone are coarse and irregularly arranged (*woven bone*), but this earlier bone is subsequently replaced by lamellar bone.

Ossification in Cartilage. Opposite the middle of the cartilaginous model (in the case of a long bone) an area of *calcified cartilage* appears in which the cartilage cells are hypertrophied and arranged in longitudinal rows. At the same time, or slightly before, the perichondrium, or periosteum as it becomes, begins to lay down bone on the surface of the shaft in the form of a thin collar. This essentially membrane bone is soon invaded by blood-vessels, osteoblasts, and larger cells or *osteoclasts*, all of which penetrate to the centre of the model, eroding and replacing the calcified cartilage on their way. Large spaces soon appear in the calcified cartilage, on the walls of which the osteoblasts proceed to deposit bone in the form of trabeculæ. In this way the cartilage is replaced by fine trabecular bone which is continuous with the outer shell of membrane bone deposited by the periosteum, and the process once established, extends up and down the bone. The medullary cavity is produced by erosion of the central bony trabeculæ, a process carried out by the osteoclasts.

Ossification commences constantly at one spot and at a fairly constant time in each individual bone, and its site is known as the *centre of ossification*. A bone may have more than one centre, in fact most have, and some have several. Such centres can be divided into *primary* and *secondary*, and as a rule the primary centres appear before birth and the secondary ones after. The secondary centres form what are called bony *epiphyses*. A bony epiphysis is a part of a bone which is developed from a secondary centre and is at first separated from the main bone, or *diaphysis*, by a connecting area of unossified *epiphyseal cartilage*; it joins the main ossification at a later date to make the adult bone. The portion of the diaphysis immediately adjoining the epiphyseal plate is known as the *metaphysis*. In some animals the epiphyses, or growing ends of the bones remain cartilaginous, and in the skeletons of many non-mammalian vertebrates secondary bony centres are absent or uncommon.

For a given embryo the centres of ossification appear in a definite sequence. For instance, in the human upper limb the order of appearance of the primary centres is as follows: humerus, radius, ulna, distal phalanges, metacarpals, proximal phalanges, middle phalanges (Noback, *et al.*, 1951). In general, secondary centres tend to appear earlier in the female than in the male.

Growth of Bone

Bone grows by a process of *surface accretion* accompanied by *erosion*. Interstitial growth of bone does not occur. The mode of action of the complementary mechanisms of accretion and erosion may be illustrated by consideration of the manner in which the shaft of a long bone increases in width. Deposition of successive layers of surface bone by the periosteum leads to an increase in thickness of the shaft. At the same time, osteoclasts working from the inner surface erode and absorb the bone with the result that the medullary cavity is widened. Further surface deposition and internal erosion continue hand in hand until the final shaft thickness and width of the bone is achieved. From this it will be clear that the compact bone of the shaft is purely periosteal in origin, and that the original shaft has been entirely eroded and replaced by the medullary cavity.

Increase in length of a bone is produced by a similar process of accretion and erosion. At birth the ends of most long bones are cartilaginous. As ossification extends from the shaft into the cartilaginous extremities, proliferation of cartilage occurs in front of it, so that whereas an increase in length of the bony shaft results, the ends remain cartilaginous. Coincident with the formation of new bone, internal erosion occurs so that the marrow cavity increases in length. It may be noted here that whereas the cartilage increases in length by interstitial growth, the bone which replaces it grows by accretion. Later, secondary centres appear in the extremities which become ossified to form bony epiphyses. These remain separated from the diaphysis by the unossified epiphyseal cartilage (Fig. 3) which continues to lay down new cartilage at its epiphyseal surface at a rate that keeps pace with the extension of ossification into its diaphyseal surface. This allows continued growth of the bone until the epiphysis unites with the diaphysis, usually at, or shortly after puberty.

Growth goes on longest at the end where the epiphysis is the last to join, and this is termed the *growing end*; in all bones except the fibula, the centre which forms the epiphysis at the growing end and therefore joins last, is the first to appear. A knowledge of the growing ends is necessary for the surgeon who may have to deal with injuries affecting them. Such injuries may cause premature junction of epiphysis with shaft, with resulting shortening and deformity of the bone concerned. The deformity, of course, will be less if the injury affects the epiphysis at the other end of the bone. The limb bones have the growing ends at the shoulder and wrist in the arm and forearm respectively, and at the knee ends of the bones in the lower limb.

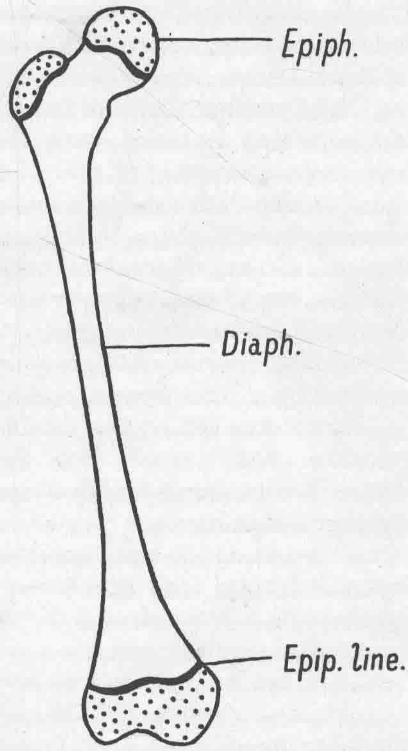

FIG. 3. Diagram of an immature long bone. *Diaph.*, diaphysis. *Epiph.*, epiphysis. *Epip. line*, epiphyseal line of cartilage.

Epiphyses are sometimes classed as *traction*, *pressure*, or *atavistic*. Those at the articular ends being in the line of weight transmission, are pressure epiphyses, and possibly serve to protect the epiphyseal plate from injury. Traction epiphyses occur opposite the sites of attachment of certain muscles and are presumed to result from the pull of these. Atavistic epiphyses are supposed to represent individual bones or processes of bones which have now no apparent function in the human skeleton, and which have become fused with, or incorporated within other bones.

It might be emphasised here that skeletal growth involves considerably more than mere absolute increase in size of bones. It includes also changes in the proportions of their various parts, and in the case of composite bony structures such as the skull, changes in the relative proportions one to another, of the individual bones. Throughout childhood and adolescence not only is there an extensive remodelling of individual bones, but also of the skeleton as a whole. The skull at birth is relatively much larger than in the adult, and the relative proportions of the cranial and facial parts is markedly different in the two instances. Changes in the relative proportions of the upper and lower limbs also occur during development. These changes are of importance in that they may be affected by various disease processes.

Little or nothing has been said here of the physiological mechanisms which initiate, influence, and control the processes of ossification and growth, nor of the many ingenious techniques which have been employed in recent years for their study. This is not to minimise their importance for a fuller understanding of these processes, but their further consideration lies outside the scope of this book. Excellent accounts of recent work in this field will be found in the papers listed at the end of this chapter.

Bony Form and Architecture

It is convenient at this stage to define the various terms given to the different markings and irregularities seen on bones.

A hole in a bone may be termed a *foramen*, *canal*, or in certain cases, a *meatus*, *hiatus*, or *aqueduct*. Prominences projecting more or less from the general level are called *processes*, *trochanters*, *tuberosities*, *protuberances*, *tubercles*, and *spines*, or, if more linear in disposition, *ridges*, *crests*, or *lines*. Depressions on the surfaces of bones may be *fossæ*, *cavities*, *fosettes*, or *foveæ*; if more linear in direction, *grooves* or *sulci*. If a large cavity exists in a bone it may be described as a *sinus*, *cell*, or *antrum*.

All the names just given are used more or less indiscriminately, but in a very general way the order in which they are placed above corresponds with the diminishing size of the different structural characters to which they refer.

A projecting articular process on a bone is frequently referred to as the *head*, its narrowed attachment to the rest of the bone as the *neck*, and the remainder constitutes the *body*, or, in a long bone, the *shaft*. A *condyle* is a protruding mass carrying an articular surface, and a *ramus* is a broad arm or process of bone projecting from the main body.

All these terms, with numerous others of more special usage will be better understood both in their meaning and application by the student after a short time spent in the study of the individual bones, and no more need be said about them now.

The Form and Shape of Bones. The factors which determine the shape and surface features of a bone may be classed as *extrinsic* and *intrinsic*. Extrinsic factors are, the pressure of surrounding structures, the pull of muscles and tendons, etc. It has already been pointed out (page 3) that bones possess an inherent capacity for self-differentiation, and bones of characteristic general shape will develop from primordia completely isolated from all other tissues. Most of the experiments on which these conclusions have been based were done on chick embryos, but Chen (1953) has shown that they also apply to mammals. It is evident then that the development of the general shape of the bones of the skeleton is determined largely by intrinsic factors inherent in the pre-cartilaginous mesenchyme of the embryo. The actual shape assumed by a given bone is a function of its phylogenetic history, and is under genetic control.

However, even at the cartilaginous stage, extrinsic and environmental factors exert an influence. For example, Chen (1953) found that fragments of undifferentiated thoracic wall removed from mouse embryos and cultivated *in vitro* gave rise to sternal bars which moved together and underwent chondrification and ossification in more or less normal fashion. Proper segmentation of the sternum however did not occur in the absence of ribs, and is therefore dependent upon their influence. Fell (1956), in summing up the results of her experiments, concludes that the influence of extrinsic factors at this stage is of importance in providing the proper environment and mechanical conditions necessary for the full realisation of normal form, and for its maintenance once attained.

While the primary build of a bone therefore is largely determined by intrinsic factors, secondary moulding of its surface is in the main due to the influence of extrinsic factors operating in late pre-natal and post-natal life. Thus, in the case of the lower jaw, the angled shape is a primary construction, while the coronoid process is largely dependent upon the muscles of mastication for its full development. The glandular fossæ of the mandible are also examples of secondary moulding. In the cranial bones the impressions of the cerebral sulci and convolutions may be seen in addition to well-marked vascular grooves. Consideration of this class of secondary mouldings will enable the student to appreciate the relation of the bone to surrounding structures, and to think of its different parts in terms of these as they exist in the living body.

In addition to the secondary mouldings just mentioned, there are *secondary markings* to be distinguished on bones. These are made by ossification spreading a little way into the attachment of fibrous tissue to the periosteum and become evident after birth, as a rule about puberty. They indicate fibrous attachment only, be it ligament, tendon, aponeurosis, or fascia, and are not made as a result of attachment of purely muscular fibres. They are manifestly surface markings, and easily distinguished from primary ridges on the bone. An excellent example is seen in the oblique, or soleal, line on the tibia, or the deltoid impression on the humerus. Such markings are not always very apparent, and in some cases may be hardly visible. In this event however, they may still be capable of being felt by the finger.

Internal Architecture of Bone. Since bones are weight-bearing structures and exposed to various mechanical stresses and strains as a result of muscular activity, it is not surprising that attempts have been made to explain the architecture of bone in terms of mechanical principles. The hollow cylindrical structure of the long bones of the limbs can obviously be compared with that of tubular scaffolding, or of the tubular steel frame of a bicycle. In the case of the latter two instances a tubular construction can be shown on mechanical grounds to be the one which best combines maximum strength with a minimum amount of material. The same principles are thought to govern the build of the bones in question which, if they were solid throughout, would be very much heavier without their capacity to resist bending strains being in any way enhanced. While this analogy seems reasonable enough, it should not be forgotten that the medullary cavities of the bones are not hollow but filled with marrow, and their hollow character is brought about by the manner of their ossification.

In many instances, *e.g.*, upper end of femur, calcaneum (Pl. 8C), etc., the trabecular arrangement of the cancellous tissue exhibits a definite pattern which is fairly constant from individual to individual. This pattern is thought to be developed in response to the forces of pressure and tension acting upon the bone, and to reflect their lines of passage through it. Numerous diagrams have been drawn by the upholders of this *trajectorial theory* which purport to show a correspondence between the theoretical lines of force passing through various bones under different conditions of stress, and the disposition of their cancellous trabeculæ. Theoretically, in a system under stress, lines of tension and pressure cross at right angles. If the trajectorial theory be correct, then the bony trabeculæ should likewise cross at right angles. The fact that they do not invariably do so, and the further fact that many of the trabeculæ appear to be very irregularly arranged would seem to contradict it. The whole question has been fully discussed by Murray (1936), and more recently by Bell (1956), and the reader who wishes to pursue the matter further should make reference to these works. All that will be said here in conclusion is, that while the arrangement of the cancellous trabeculæ would appear in a very general sense to be adapted to stress and weight-bearing strains, it is extremely difficult to find convincing proof that this is, in fact, the case.

Most of the experiments which have been devised in an attempt to relate the architecture of bones to the forces operating upon them have of necessity, taken place at an ontogenetic level, *i.e.*, during the lifetime of an individual animal. In interpreting the results of such experiments, it is as well not to lose sight of the fact that the structure of an animal's bones is not entirely conditioned by forces operating during its own lifetime. Much of it is already apparent at an age long before that at which such forces even begin to operate, and is obviously determined by hereditary factors. This being the case, it is very probable that a consideration of the comparative anatomy and phylogenetic history of a bone may yield important information about its structural adaptation, of a character which cannot be investigated by experiments carried out at an individual level.

JOINTS

Joints are probably best classified according to the amount of movement they permit. On this basis, we can distinguish *diarthroses*, or freely movable joints, and *synarthroses*, or joints where no movement is permitted. A third group, the *amphiarthroses*, comprises joints where only a very slight amount of movement occurs.

Diarthrodial joints (Fig. 4) possess a cavity lined by *synovial membrane*, and this cavity may be wholly or partially divided by an intra-articular cartilage, or *meniscus*, into two parts. The synovial membrane secretes a fluid which serves to lubricate the cartilage-covered articulating surfaces, and it lines the inner surface of the *fibrous capsule* which binds the bones together, as well as any intra-capsular portions of the bones up to the margins of their articulating surfaces. In some synovial joints, *e.g.*, elbow and knee, fatty pads are found between the synovial membrane and the articular capsule. These, apart from any purely space-filling function, are thought (MacConaill, 1950) to assist lubrication by influencing the thickness of the film of synovial fluid.

In synarthrodial joints, the articulating elements are united either by means of fibrous tissue (*sutures*) or by hyaline cartilage (*synchondroses*). The majority of these joints are developed for the specific purpose of allowing skeletal growth to occur, *e.g.*, the joint between the epiphysis and diaphysis of a long bone, and become obliterated when this is completed. In the case of amphiarthroses, when the bones are directly united by fibrous tissue, the joint is called a *syndesmosis*, and a *symphysis* is another variety of amphiarthrosis in which fibro-cartilage unites bony surfaces each of which is covered by a thin layer of hyaline cartilage.

Ligaments are bands of fibrous tissue that pass over joints to hold the bones together. They may appear as localised thickenings of the articular capsule, or be completely separate from it, in which case they are classed as intra- or extra-capsular accessory ligaments of the joint. In addition to holding the bones together, ligaments may be further concerned with limiting their movements in various directions. Depending upon its disposition in relation to the axis of movement of the joint, a ligament may be tense and effective at one part of the movement, or it may remain tense throughout. Equally well, some of its fibres may be taut in one position of the joint, and a different set in another position, the net result being that some fibres are taut throughout the entire movement.

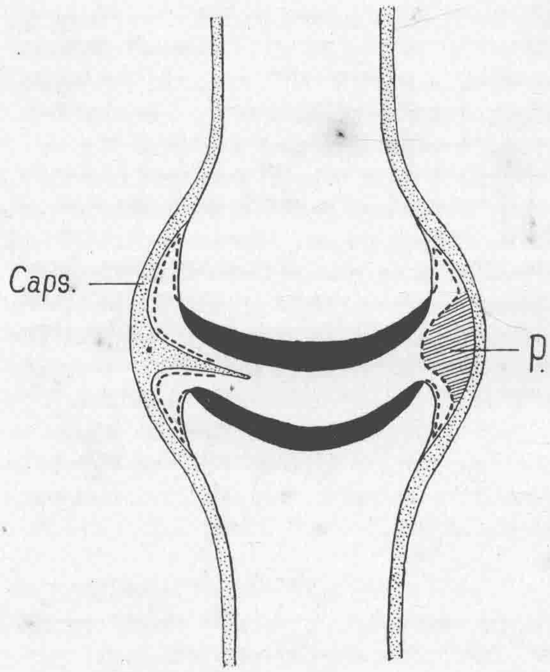

FIG. 4. Diagram to show the essential features of a synovial joint. The articular cartilage is in solid black, and the broken line represents the synovial membrane. On the left-hand side, an incomplete intra-articular disc is shown projecting into the joint-cavity. *Caps.*, fibrous capsule of joint, continuous with periosteum (stippled). *P.*, pad of fat, which is intra-capsular, but extra-synovial in position.

Joint ligaments are commonly thought of as being inelastic, and indeed this would appear to be a necessary requirement if they are to fulfil their functions properly. However, there is some evidence to show that despite the absence of elastic fibres, ligaments can undergo a considerable amount of stretch without being permanently lengthened. Smith (1954) for instance, found that the anterior cruciate ligament of the rabbit could be temporarily extended by as much as 20 per cent of its original length. Under normal conditions in the living, the ligaments are protected from forces which might overstrain them by the contraction of the muscles acting over the joint, and in fact, in the long run the maintenance of joint stability is dependent more upon muscular than upon ligamentous control. This is true at any rate in the case of some of the weight-bearing joints of the lower limbs, and in such joints as the shoulder, where the bony surfaces are but poorly adapted to each other, and where the articular capsule is relatively lax.

PLAN OF THIS BOOK

In the account of the skeleton that follows, each bone is at first described shortly, and a reader approaching the subject for the first time ought to go carefully through the description with the bones beside him, until he is acquainted with the general build and form of the particular bone, and the names, position, and nature of all its principal parts.

A more detailed consideration of the bone then follows. Such a consideration could not be understood unless the reader had dissected the part concerned, so it is assumed that he has done so, and is more or less familiar with it.

The key to many things that puzzle the student of anatomy is to be found in the study of the bones of a part, and it should be a rule for every dissector that he must undertake his dissection with the skeleton of the region beside him, so that he may constantly refer from one to the other and back again. In this way he will begin to understand why certain structures are found in certain situations, and to look at them from new points of view. He should bear in mind that the disposition of the soft parts has its effect on the structure of the bones and he should look for this as much as for the effect that the bones produce in the arrangement of the tissues. In this way he will obtain an idea of the skeleton as it exists in the body, with all its attachments and relations—a much more interesting study than that of the dry bones.

When considering bones or reading descriptions of them, the student should take care to have the specimens before him. A description that is not verified is of little permanent value, and the reader ought to make a point of referring every statement made in the description to the test of observation on the specimen. For this reason he should be provided with several examples of the particular part of the skeleton he is studying, for comparison between many specimens is the best way of impressing the main points of any structure on the mind, in spite of individual variations. Also, whenever it is possible he ought to have the appropriate dissections and preparations that enable him to appreciate the bones *in situ,* and constant reference to these will be of the utmost benefit. Finally, he should always see how much of the skeleton can be felt and studied on his own or some other living body.

After these remarks it might seem superfluous to stress that the descriptions of the bones given here are intended for application to actual specimens, and not to the drawings. The majority of the figures in the following pages are introduced mainly as guides to facilitate the recognition of the various parts of the skeleton. There can be no other object in having drawings of bones, and Anatomy cannot be learnt from pictures alone.

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CHAPTER II

VERTEBRAL COLUMN

GENERAL

The human spinal column is made up of some thirty-three segments or *vertebræ:* the length of the column of bones is much increased by *intervertebral discs* of fibro-cartilage placed between the segments.

The column has two main functions—(*a*) support of the trunk, etc., and transmission of its weight to the pelvis and lower extremities; (*b*) protection of the spinal cord and its membranes. The structure of the whole column accords with the necessities of these functions, and thus the vertebræ of which it is composed show their individual agreement with the general arrangement of the whole: they are modified in details according to their position, but they are all built on the same general principle.

This principle may be followed on a vertebra taken from the centre of the column and used as an illustration of the positions of the chief parts of a "typical" vertebra.

Typical Vertebra (Fig. 5). In front a strong *body* carries and transmits weight, while the *vertebral arch* behind this covers in the spinal cord: in conformity with this we find the

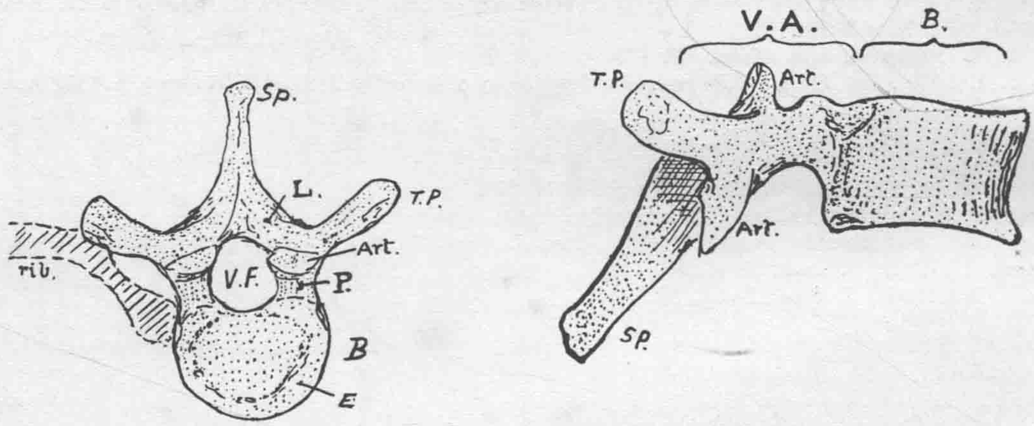

FIG. 5. A "typical" vertebra (mid-thoracic). From above and from the side. B., body; *V.A.*, vertebral arch; *V.F.*, vertebral foramen; *Sp.*, spinous process; *T.P.*, transverse process; *L.*, lamina; *P.*, pedicle; *Art.*, articular process. A rib is also indicated in position on one side. *E.*, is the "epiphyseal plate" or ring on the body.

strong pads of the intervertebral discs placed between the bodies of contiguous vertebræ, whereas the arches are connected by ligaments and tend to overlap one another.

In the articulated column the successive arches and ligaments, with the backs of the bodies, enclose a *neural* or *vertebral canal* for the cord and membranes, and the portion of the canal that is enclosed in the neural arch of each separate bone constitutes the *vertebral foramen* of that vertebra.

The vertebral arch has *spinous* and *transverse* processes projecting from its back and sides respectively, for the attachment of muscles and ligaments: the transverse processes also help to support ribs in their attachment to the column. Each half of the vertebral arch is divided by the position of the transverse process into a posterior part between this process and the spine, termed the *lamina*, and a portion in front between the process and the body, which constitutes the *pedicle*. These two parts are under somewhat different conditions: the pedicles are thick and somewhat rounded bony bars transmitting to the body the weight