Journal of Anatomy and Physiology.

ON THE GROWTH AND MAINTENANCE OF THE ARTICULAR ENDS OF ADULT BONES. By ALEX. OGSTON, M.D., *Surgeon to the Aberdeen Royal Infirmary.*[1] (PLATES IX. to XVI.)

IN the year 1875, in the tenth volume of this *Journal,* I had occasion to lay before the profession the results of some investigations into the structure and functions of articular cartilage, and these results contradicted the hitherto universally received opinions on these subjects.

They showed that, instead of the articular cartilages being mere cushions to diminish shock and render motion smooth, they were really a growing tissue, possessing most important functions. The cartilages were demonstrated as being formed of cells in active, constant, and definite growth, protected against being crushed or injured during the normal movements of the bones and limbs by being imbedded in an elastic, very resistant, hyaline matrix. Evidence was adduced that the cartilages grew from their centre towards the joint cavity on the one hand, and towards the bone on the other hand; that towards the joint cavity the cartilage became effete and was worn down, and towards the bone it became developed into bone, by a transformation identical with that by which the epiphysal cartilages produce elongation of the shafts of bones during the period of their development. The structure and functions were traced, so far as was then possible, both in health and disease, and it was shown that, under all circumstances, articular cartilage possessed the same rank as periosteum in being constantly engaged in producing new bone.

[1] Read before the Aberdeen Branch of the British Medical Association, 1st May 1878.

Since that paper was published an extensive series of investigations concerning cartilage have been, as opportunity offered, carried out, and the result has been to show, more and more convincingly, the correctness of these views. At present the specimens and facts at my disposal warrant me, I believe, in asserting, more strongly than before, that articular cartilage is as valuable and necessary in forming and maintaining the structure and shape of bone as periosteum is always admitted to be.

Further, the same function of producing new bone is constantly being exercised by the costal cartilages, the intervertebral cartilages, and most, if not all, cartilages in connection with the skeleton that are not classed as being, strictly so called, articular.

Moreover, cartilage discharges a considerable portion of the work that has hitherto been assigned to other structures, and can be demonstrated, as I shall presently try to show, as being the producer of very large portions of the bones—larger portions, indeed, than I had believed to be the case at the time that the former paper was written.

The former paper was an attempt to show that articular cartilage forms bone, and to demonstrate the processes by which it forms it. The present paper has to deal with the extent to which bone is thus formed.

Most, if not all, the cartilages in connection with bones seem to be concerned in bone growth, even those that are not articular cartilages proper. The changes and appearances described in the former paper as indicative of transformation into new bone are found with the microscope not only in the ordinary articular cartilages, but also, distinctly and unmistakably, in the costal cartilages at the anterior ends of the ribs, in the intervertebral cartilages, &c., &c., and at all these points, as well as in the ordinary joints, addition to the length of the bone is constantly going on. The microscopical appearances indicating transformation of cartilage into bone were fully described in the former paper, and need not be entered on again here.

In order to ascertain how much of a bone is produced from cartilage, it would be desirable to possess some mark by which we could recognise bone produced in this manner, and distinguish it from that having some other origin.

The microscope shows, and the naked eye confirms the observation, that there is a peculiarity about the bone produced by cartilage that permits of its being readily distinguished from that which has a periosteal origin. The former sort of bone is marked out by the main beams or trabeculæ of its meshwork being placed at right angles to the bone surface, while periosteal bone is characterised either by its main trabeculæ being parallel to the bone surface, or by there being no indication of any special direction observable in them at all.

A vertical section of the head of the tibia, for example (Plate X. fig. 1), shows underlying the articular cartilage a mass of bone, spongy in its structure, and therefore possessing trabeculæ running in many directions, but with its main and strongest trabeculæ running almost regularly parallel to each other in one fixed direction, and that direction is at right angles to the joint surface of the bone (Plate IX. *a*). And wherever else we find cartilage showing microscopical evidence of its being transformed into bone, we find the bone underlying that cartilage invariably presenting the characteristic striation at right angles to the surface. The very sinuosities of cartilaginous surfaces bring this out even more distinctly, for they cause a little deviation or obliquity of the trabeculæ corresponding with them; but whatever the deviation, the striation of the bone remains at right angles to the surface that has produced it.

Curiously enough, an apparent exception that is sometimes noticed gives, when investigated, an additional proof of the correctness of this rule. At the margins of articular facets, the main trabeculæ are frequently directed, not at right angles to the surface, but obliquely, sometimes even at an angle of 45°. In most situations where this exists, the microscope shows that the direction of the rows of cartilage cells is oblique too, and the obliquity usually corresponds with that of the trabeculæ, so that the direction of the trabeculæ, if prolonged, would correspond with that of the cartilage-cell rows, and be therefore at right angles to the plane of growth.

Periosteal bone, on the other hand, usually shows a striation parallel to the surface of the bone. In the compact tissue, which arises from periosteum, it is well known that the Haversian systems run parallel to this membrane, while the rows of bone corpuscles can be seen to follow the same arrangement, and the naked eye can readily trace a like parallelism. But it often occurs that periosteum produces spongy bone, as in the trochanter major, the os calcis, &c. Such periosteal bone shows, as a rule, the same parallel arrangement. Starting from the surface, and going gradually into the centre of the bone, are seen masses of spongy tissue (Plate IX. *c*), characterised by distinctly marked strong trabeculæ, arranged parallel to the bone surface. Where periosteal bone does not present this parallel striation the trabeculæ may be indefinite in direction (Plate IX. *b*), and present an appearance similar to that seen in a section of a sponge; but they never present the distribution at right angles to the surface that seems to be characteristic of bone which has originated from cartilage. (Plate IX. *a*.)

Wherever bony tissue exists, it is possible, by observing these peculiarities, to tell what is its origin—whether it be, in fact, chondrogenous or periosteal. In sections of fresh bones the presence of the medulla may make it somewhat difficult to do so, as it renders the bone-markings less clear. In a dried bone it becomes easier, and in a well macerated bone it is quite easy. But in any part of any bone the distinction is always, with proper care, observable; and it can in the most difficult cases be at once rendered evident by calcining a section to a white heat until nothing remains but the bright white calcareous structure. Such a distinction between periosteal bone and bone produced from cartilage, or chondrogenous bone, as I have ventured to call it, is of the very highest importance—and I wish to emphasise this as one of the main points in the present paper, since it throws a great flood of light upon the question, still unsolved by physiologists, as to how the bones grow and continue to exist.

At present we know that in young and growing individuals the shaft of the long bones is formed by new bone added to the exterior by the periosteum, and to the ends by the cartilages of ossification; but we do not know how the epiphyses are produced, unless it be from the periosteum covering their sides.

In mature and adult bones we know that the compact tissue of the shaft is continually, though slowly, receiving new bone from the periosteum around it, and grows towards its centre, where it is absorbed by the medulla in the medullary cavity; and that partial interstitial absorption, by means of the Haversian systems, is also constantly going on. But the compact tissue of the shaft, and the medulla in the central cavity, do not themselves, in the adult, possess any power of forming new bone. If, for example, a perforation is made through the shaft into the medullary cavity, new bone appears growing inwards from the periosteum, filling the perforation and extending into the medulla; but if the perforation be filled up or covered by a plate, so as to prevent the periosteum producing this effect, no production of new bone results in the aperture or in the medulla.[1] The medulla in the central cavity is well known to possess great powers of absorption, evincing these, both in health and in disease, to such a degree that it has sometimes been placed on a par with the absorbent system generally. Hence it is believed that, in the shafts, centripetal growth, with partial interstitial absorption, and final absorption by the medulla in the medullary cavity, are constantly going on; and that new layers are continually being added to the exterior by the periosteum, save at certain points of the surface where absorption has been found by some observers to be taking place. But beyond this our knowledge does not go. We do not know whence the spongy bone in the epiphyses comes. It has been assumed to come from the periosteum; but this is a mere assumption, destitute of even an attempt at proof. It has been assumed, on the other hand, that it comes from the red medulla occupying the interspaces. There seems to be some reason for believing that the red medulla, in young and growing individuals, *may under certain circumstances* produce bone, though this is far from proved; but in the adult it does not normally do so. The experiments of Bidder[2] of Mannheim seem to me conclusively to establish that point, and to render untenable the belief that the spongy bone in the epiphyses arises from its own medulla. Bidder bored through the epiphyses from the articular facets into the medullary cavity, but failed by this, by irritating the perforations by ivory pegs, or by scooping out the epiphyses through the perforations, in obtaining any new bone formation,

[1] Maas, *Arch. f. Clin. Chir.* Bd. xx. Heft 4.
[2] Bidder, *Arch. f. Clin. Chir.* Bd. xxii. Heft 1.

while similar perforations through the periosteum are known to produce abundant ossification.[1] The almost universal belief throughout the profession at present is that the layer of bone underlying the articular cartilage is the source of the epiphysal spongy osseous tissue; but this, too, is a hypothesis unsubstantiated by even a vestige of proof. It is a fact that our knowledge of the laws concerning the production, maintenance, and absorption of normal adult bones is at present in a state of great confusion, and can scarcely be said with truth to exist at all. We want something to enable us to piece together the scraps of knowledge we possess.

On studying the internal architecture of bones, with the knowledge that portions of them are produced by the articular cartilages, and that these can be distinguished from the other parts, the obscurity overhanging the subject is very considerably diminished. We can recognise almost at a glance that all the surfaces, whether periosteal or cartilaginous, are constantly being renewed by the deposition of new layers of osseous tissue. We can see that the osseous tissue so formed grows inwards, that is, centripetally; that where the masses growing inwards meet each other, there is absorption of them by the red medulla; and that when the parts that are spared by this process reach the medullary cavity, they there complete the life history of bony tissue by being absorbed in the central medullary sea.

These generalisations are irresistibly forced upon us when we examine in detail the internal structure of the bones; and it will now be convenient, as types of the bone growth, to enter a little more fully into the appearances observed—1st, in the articular ends of ordinary long bones; 2d, in bones mostly covered with cartilage; 3d, in bones mostly covered with periosteum; and

[1] Bidder's experiments may seem to contradict my assertion that articular cartilage produces bone, as it may not unnaturally be asked, Why does not a perforated cartilage, like a perforated periosteum, react in producing new bone? But the contradiction is only apparent, not real. Cartilage, unlike periosteum, cannot, in a short space of time, proliferate laterally (its texture forbids it); it grows only towards the epiphysis; and if a portion be removed in making a perforation, the neighbouring portions cannot proliferate towards or into the perforation. That articular cartilage under irritation is really analogous with periosteum in producing an overgrowth of new bone in its own way, is sufficiently shown in my former paper when considering its behaviour in scrofulous arthritis.

lastly, in some peculiarly complicated bones, such as the head and upper part of the femur.

First, Typical long bones, such as the tibiæ, phalanges, ribs, &c., possess as their integuments a tube of periosteum covering and producing their sides, and variously shaped pieces of cartilage covering and producing their ends.

In the ends of all such long bones there is a considerable variation in the distinctness with which the appearances to be described can be discerned; but they are present in all, and can, with sufficient care, always be made out. Lining the sides of the tibia (which may be taken as a type of the other long bones), we find (Plate X. fig. 1) a hollow cylinder of compact osseous tissue produced from the periosteum, and showing, therefore, a striation parallel to the surface. At the epiphysal ends this cylinder expands into a hollow cone, the centre of which is filled by a mass of chondrogenous bone, marked, as might be expected, by the characteristic striation at right angles to the disk of cartilage. This chondrogenous mass of bone preserves its characteristic features until, in its progress from the articular facet to the medullary cavity, it either comes in contact with the yellow medulla lying there, or is wedged against the sides of the gradually narrowing hollow cone of periosteal bone. At both these places it stops, and evidently proceeds no further, but undergoes, in some manner or other, a process of absorption. The process by which this absorption takes place is far from being so evident as might be desired. The nearer they approach the central point of absorption in the medullary cavity, the more slender do the bony trabeculæ become, and the larger are the cavities between them containing the buds of red medulla, showing that interstitial absorption is a feature in the life of the spongy as in the life of the compact tissue. But even the slenderest of the trabeculæ, where they are just on the point of disappearing by absorption, shows none of the Howships lacunæ and polynucleated cells or osteoclasts, which often, under other conditions, indicate that absorption is going on. Probably the process by which normal medulla absorbs normal bone differs from the process of pathological absorption, and gives less distinct microscopic evidence of its existence. But that absorption actually takes place is evidenced by the progressive attenuation of the trabeculæ as they approach the points where they disappear.

Besides the medullary cavity proper, there are other and supplementary points at which absorption of bone is in full activity. At certain places the chondrogenous bone impinges on the compact periosteal bone lining the sides of the tibia; at others, the tibial cartilage, not being a perfect plane, produces masses of bone, which, owing to the direction of their growth, impinge on one another, and on bone that can be recognised by its markings as coming from the periosteal tissues, near the crucial ligaments, *i.e.*, between the two halves of the articular surface. Wherever such masses meet, we find (Plate X. fig. 1, *a*) a rarefied spot in the spongy tissue, furnished with a large vein, filled with larger buds than usual of the red medulla, and forming as it were a supplementary medullary cavity. These rarefied spots are in fact miniature medullary cavities, and are engaged in the absorption of bone.

The study of the growth of such long bones, therefore, bears out, and that very strongly, the assertion that the articular cartilages may claim a much more important place as formers of bone than has hitherto been conceived, inasmuch as they produce almost the whole of the bulky epiphysal ends, and maintain their size and form, despite the adverse influences constantly at work upon them.

Judging from the variations in activity displayed by the cartilages, the rate of bone growth varies much in different joints, being greatest in those where pressure is most marked, as in the knee and hip, and least where it is inconsiderable, as, for instance, in the phalanges.

What the actual rate of growth is in any individual bone is a most difficult question, and one I am not as yet prepared satisfactorily to answer. But it must be very slow, if the activity of proliferation displayed by the microscope in the cartilages be taken as evidence; since no cartilage at all approaches in activity to the cartilages of ossification which, in the growing individual, produce the increase in length of the shafts, and yet that is itself a process far from rapid, as is well known.

In my previous paper I have shown that under pathological conditions the rate of growth is occasionally very rapid.

Second, The integuments of some bones consist mostly of articular cartilage. Many of the carpal and tarsal bones belong to this class, and the astragalus, which may be taken as a good type, shows cartilage clothing more than half its superficies. A vertical antero-posterior section presents four-fifths of the astragalus invested with cartilage, and only one-fifth with periosteum. Such a section (Plate X. fig. 2) exhibits a striking contrast to that of a periosteum-clad bone. Nearly everywhere the trabeculæ are arranged at right angles to the surface; the slight exceptions being at places covered by periosteum, where the usual periosteal bone is found. The chondrogenous bone passes inwards to the centre, and there the usual absorption space is found. Minor absorption spaces are scattered about wherever masses of bone disagreeing in direction come into mutual contact.

Third, Bones covered mainly by periosteum show a structure which is the direct antithesis of the preceding. Such bones are numerous. The scapulæ, ossa innominata, &c., are good examples, but some of the smaller bones, and particularly the calcaneum, are more convenient examples of the facts I am concerned to illustrate. If the os calcis be divided vertically (Plate XI. fig. 1) in the antero-posterior direction, most of the margin of the section is bounded by periosteum. Some small portions of it are cartilaginous, and from them the usual chondrogenous masses pass inwards. Elsewhere the striation is parallel to the periosteum, and the layers pass inwards to reach the absorption spaces.

The periosteal bone of the calcaneum presents, however, a peculiarity to which I must draw attention here, and which will be found to have a further bearing in studying the next class of bones. This is, that the periosteal bone, as it passes inwards, frequently deviates from its original parallel distribution. If we could suppose a bone entirely covered with periosteum, and unsubjected to any influence from without, such a bone would show its periosteal bone passing inwards in layers that would preserve their direction parallel to the surface. Such a phenomenon is witnessed, more or less perfectly, in periosteal bones subjected to little external pressure. But where a bone has to bear great weights things are different. The os calcis has to support the whole body. Through the astragalus the weight is transferred downwards towards its upper surface, while its lower surface is constantly encountering an equivalent pressure from the ground in the opposite, that is, the upward direction. The upper and lower surfaces are thus, in fact, squeezed together, or driven towards each other every time we stand or walk; and this pressure is strongest at the back part, the tuberosity, which alone comes in contact with the ground. This back part has its upper and lower surfaces strongly driven towards each other, the lower by the direct pressure of the ground, the upper owing to the oblique way in which the force is communicated to it from the astragalus. The compression, greatest posteriorly, diminishes gradually towards the anterior end of the bone. This pressure, while probably creating an increased periosteal activity, determines a deviation inwards of the layers of bone, and the deviation is greatest where the pressure is strongest. Hence the layers as they pass inwards become oblique, the obliquity being greatest behind, and the two masses of bone, oblique in opposite directions as regards each other, become somewhat dovetailed or forced into one another. This obliquity of periosteal bone is a factor we shall subsequently have occasion to notice, and always in bones that are subjected to considerable pressure from without.

Fourth, The last class of bones to which I would ask attention consists of complicated bones, where the forces at work, and the amount and direction of the pressure influencing them, are peculiarly complicated, or display at least something unusual. The theories I have advanced, though they do not explain everything, give a considerable insight into much that has hitherto been far from clear regarding complicated bones.

Under this class I propose to limit myself to considering the upper part of the os femoris. In the head and neck of that bone there are curious markings that have puzzled anatomists. In anatomical works an incorrect woodcut of these markings is usually given in a diagrammatic form, and it has been asserted that they form a peculiar architectural design to strengthen the bone in the directions in which it needs stability. This theory, however, has been shown to be incorrect and inadequate on purely mathematical and mechanical grounds.

I have drawn up a correct diagram of the markings (Plate XI. fig. 2), the correctness of which may be ascertained by comparing it with sections of the bone. In it you see periosteal bone produced in the neck and trochanter major, and masses of chondrogenous bone in the head. The chondrogenous bone radiates with the greatest regularity towards a common centre in the head. The peripheral parts of this cartilage bone, that is, those nearest the margin of the articular facet, soon end in absorption spaces, but the middle part, that is, the portion nearest the ligamentum teres, grows inwards until it meets the bone produced by the lower side of the cervix.

Here I must digress a moment to consider the lower surface of the neck of the femur.

The forces acting on the upper part of the femur are twofold. There is a nearly horizontal force acting along the long axis of the neck, and which tends to approximate the trochanter major to the acetabulum. There is also a nearly vertical force, which would find its best expression in a tendency to carry the caput femoris downwards, and the cervix femoris upwards, the one past the other. The resultant of both forces falls in a line neither horizontal nor vertical, but intermediate between them, oblique in direction, and passing along or near to the lower surface of the neck. At this spot we find a special provision to resist these forces. The strain at the part is great, and, accordingly, the periosteal activity is very great too. This is evidenced by the thick layer of compact bone found on the lower side of the neck. By the above-mentioned forces this dense bone is by degrees forced up into the head of the femur, and it there meets and becomes continuous with the central part of the chondrogenous bone as *it* grows inwards. Both of these masses correspond with each other in the direction of their striation, and blend into a column of considerable solidity, passing from the vicinity of the round ligament to the lower surface of the neck.

A further action of the two forces above mentioned is seen as we go downwards along the cervix femoris. The vertical force acting in pushing the head of the femur downwards, is transferred from it to a considerable degree to the upper surface of the neck, forces down there the plates of periosteal bone, and bends them inwards towards the centre, just as was seen in the os calcis, while from the lower surface of the neck the layers are in like manner forced in the reverse, *i.e.*, the upward direction, by the forces acting from below, the tendency being (to use the expression already applied to the calcaneum) for the upper and lower surfaces of the neck to be forced into mutual contact. All this produces an interlacing or dovetailing of the periosteal plates proceeding from the upper and lower surfaces of the neck. The additional bone which is constantly being added from the caput femoris passes towards the medullary cavity of the femur along with these interlaced plates, and as all in common advance along the neck, the layers are gradually turned over, like the leaves of a book, until they even come to be at right angles to the direction they originally occupied and theoretically ought to have kept. Such seeming exceptions to the general rule concerning the striation of periosteal bone are, in reality, no exceptions, but even afford, when rightly understood, a further insight into the laws that regulate the growth of bone.

In all the bones of the human frame, as well as in those selected above to be dwelt upon in detail as types of various classes, the same facts concerning chondrogenous and periosteal bone are exemplified and borne out. Everywhere the markings of the interior of bone are recognisable as being due to the laws that have been stated, and not to any other external or internal cause that is discoverable. To avoid tediousness and needless repetition, plans (Plates XII. to XV.) have been drawn up of the structure of a number of bones, where, as in those already referred to, the periosteal portions are indicated by red, and the chondrogenous by blue lines. The corresponding sections of the bones themselves may be compared with the diagrams, and will vouch for their correctness, although I must again emphasise that the markings are not equally distinct in every bone. Nevertheless, with care and proper preparation, they can always be made out.

In the glenoid cavity of the scapula (Plate XIII. fig. 7), in the bodies of the vertebræ (Plate XIII. fig. 3), and in the acetabulum (Plate XIV. fig. 3), the chondrogenous bone is unusually coarse, but is wanting in no essential characteristic. The contrast between chondrogenous and periosteal bone in the bottom of the acetabulum is especially worthy of note.

In examining bones generally it is not always easy to say *exactly* where cartilage bone ceases and periosteal bone begins, in the central parts where they come into contact, and a difference of opinion may now and then be expected. But I think myself warranted in saying that every suitable section will be found to bear out in principle the opinions advanced in this paper. As an illustration of how much reliance may be placed on the appearance of bone structure, I may mention that in one instance I was led by it to discover the existence of cartilage in a situation where it is not generally known to be present. In preparing a sagittal section of a dorsal vertebra (the one sketched in the diagram, Plate XIII. fig. 3), the peculiar appearance of the spinous process led to the belief that its tip must have been coated with cartilage which had given rise to the characteristic bone beneath. A reference to the ordinary works on anatomy gave no hint of its existence there; but on examining with the microscope the fresh spinous processes of a lumbar and dorsal vertebra, the former was found coated at its tip by fibro-cartilage, and the latter by true hyaline cartilage.

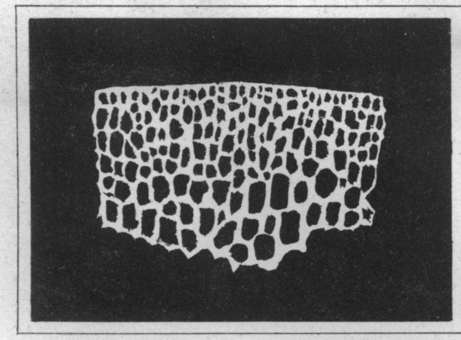
The cartilage, then, that is found covering the surfaces of bones produces the osseous tissue beneath it, forms the epiphyses, supplies their waste, and maintains them in their proper size and bulk during adult life. But cartilage forms no exception to the rule that in old age all tissues diminish in vitality and vigour. The articular cartilages of old people approach in structure, as age advances, more and more to fibro-cartilage. They then offer evidence of diminished growth, and as a natural sequence it may be expected that the ends of senile bones would offer some signs of this diminution of activity. Nor are these wanting. The general surfaces of senile joints are flatter, and not so full and plump in their curves; the grooves of articulation with opposing bones are deeper and more marked, and the different shapes of the articular surfaces are such that they are readily recognisable by the eye, and even better followed when depicted in a diagram.

In comparing the knee-joint of an adult with that of an old person (Plate XVI. figs. 1, 2, 7, 8), the curves of the condyles are flatter, the groove for the patella is broader and more distinct on the femur, and lies more on its external condyle; while the hollows on the top of the tibia are less marked in the aged than in the adult subject.

In the ankle-joint again (Plate XVI. figs. 3, 4, 5, 6), the upper surface of the astragalus is higher in the older subject, as if it had been forced further upwards between the malleoli by long use; and a longitudinal groove, unobservable in the younger joint, is found to have made its appearance. These changes are better seen in the accompanying drawings, where the surface curves are represented together as they were found in the knee and ankle-joints of a subject of twenty-five and another of sixty years of age. The curves of the younger person are drawn in red, those of the older subject in black.

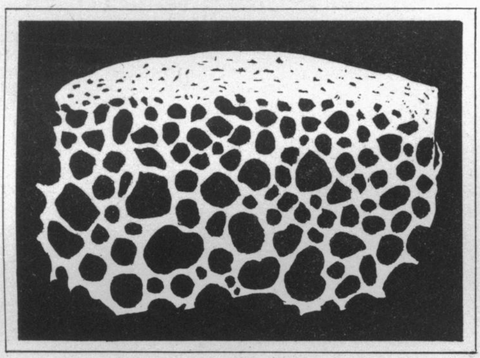
In the present paper I have confined myself to adducing facts and appearances as presented in normal anatomy, and have considered the subject solely from a physiological point of view. From pathological observations I could adduce a wide series of facts quite as conclusive and supporting as distinctly the truth of what has been asserted. But this would lead me far beyond the limits I have proposed to myself on this occasion, and I must reserve the evidences furnished by such sources to another opportunity.

a



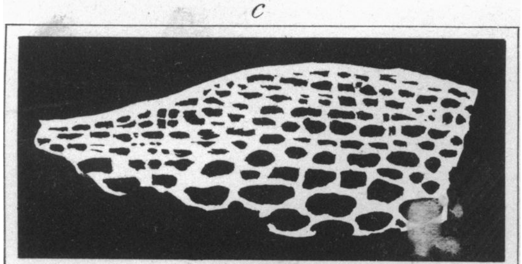
Chondrogenous Bone.

b



Periosteal Bone.

c



Periosteal Bone.

Fig. 1.
Head of Tibia.

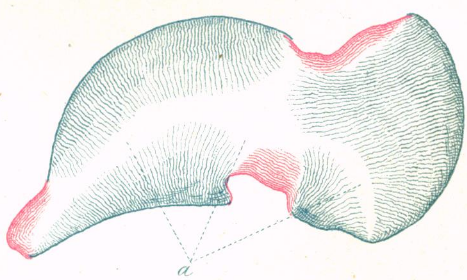


Fig. 2.
Sagittal Section of Astragalus.

Periosteal bone,-Red: Chondrogenous bone,-Blue: a: Absorption spaces.

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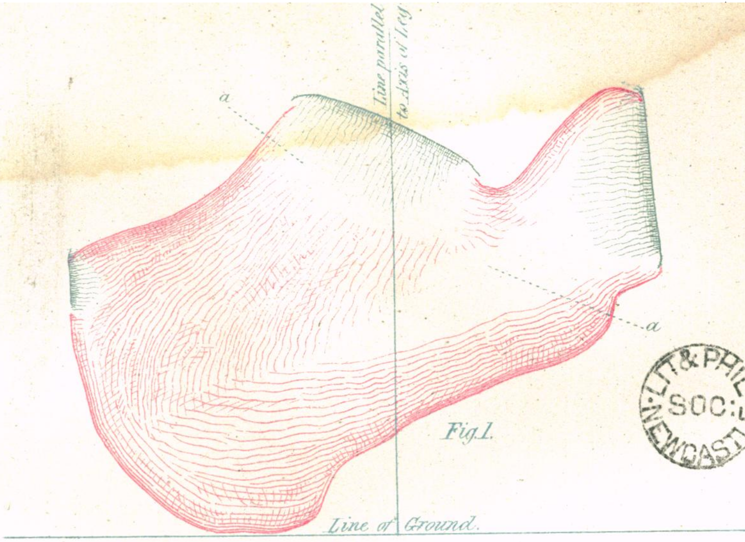


Fig. 1.

Vertical Sagittal Section of Calcaneam.

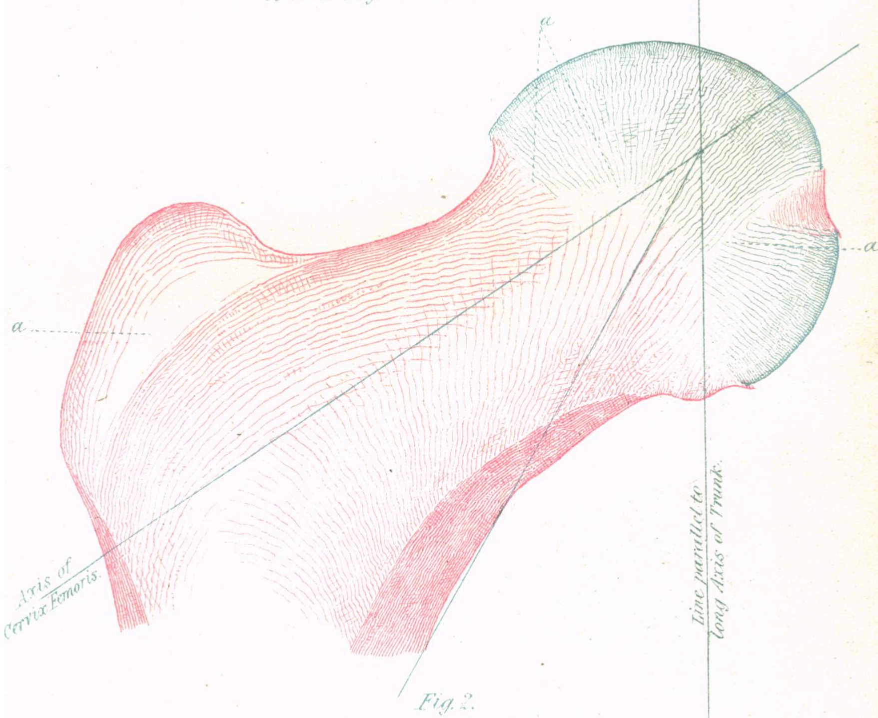


Fig. 2.

Head and Neck of Femur.

Periosteal bone, Red; Chondrogenous bone, Blue; a Absorption spaces.

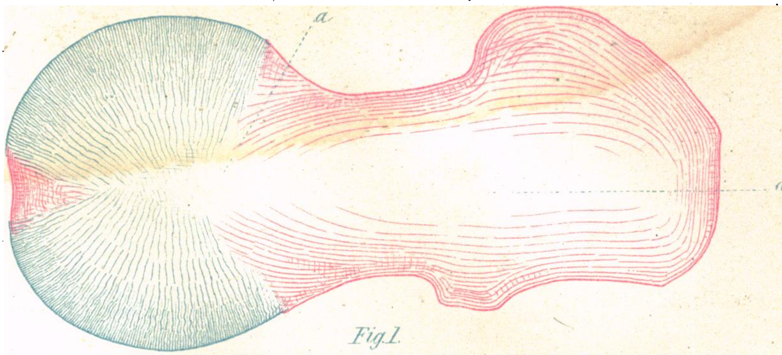


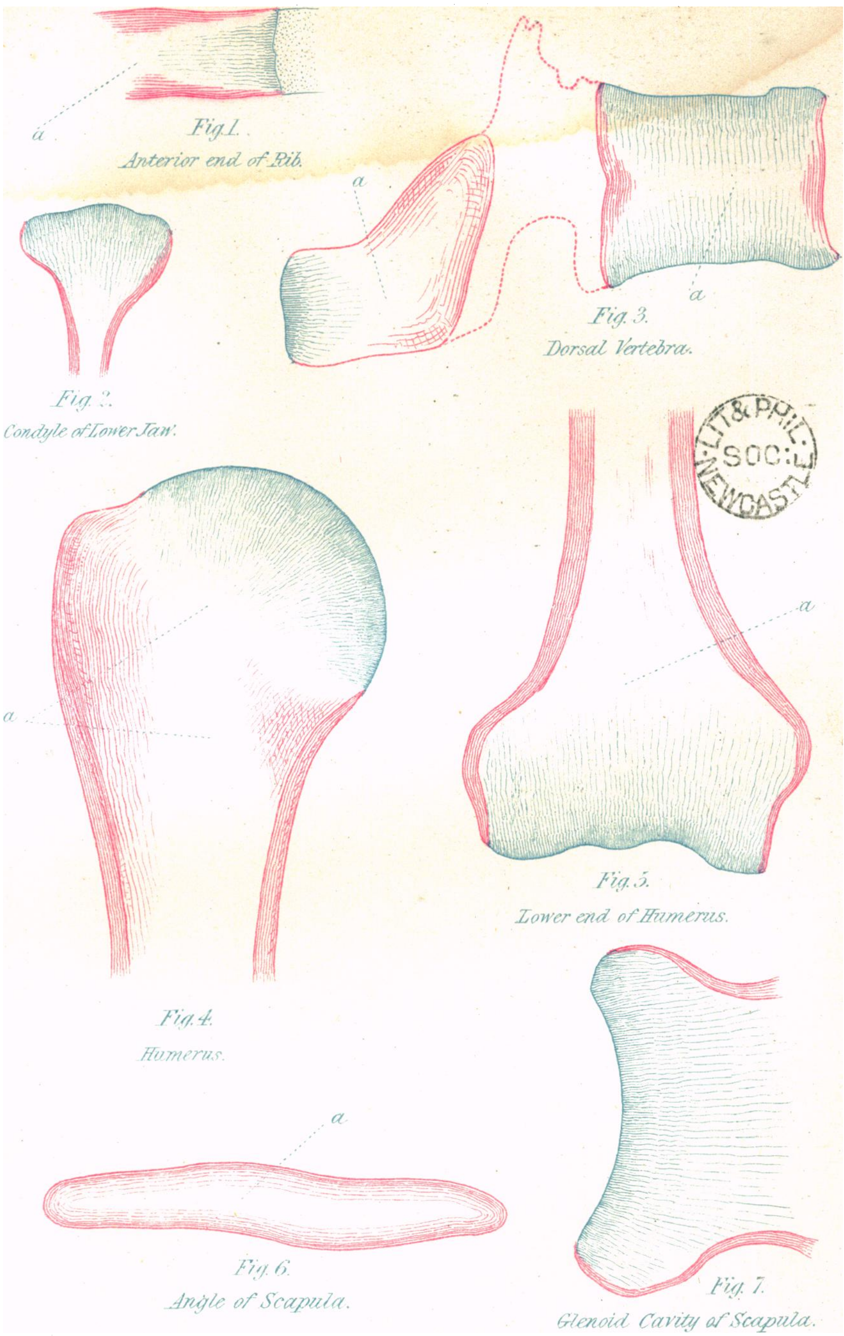
Fig. 1.

Horizontal Section of Head and Neck of Femur.

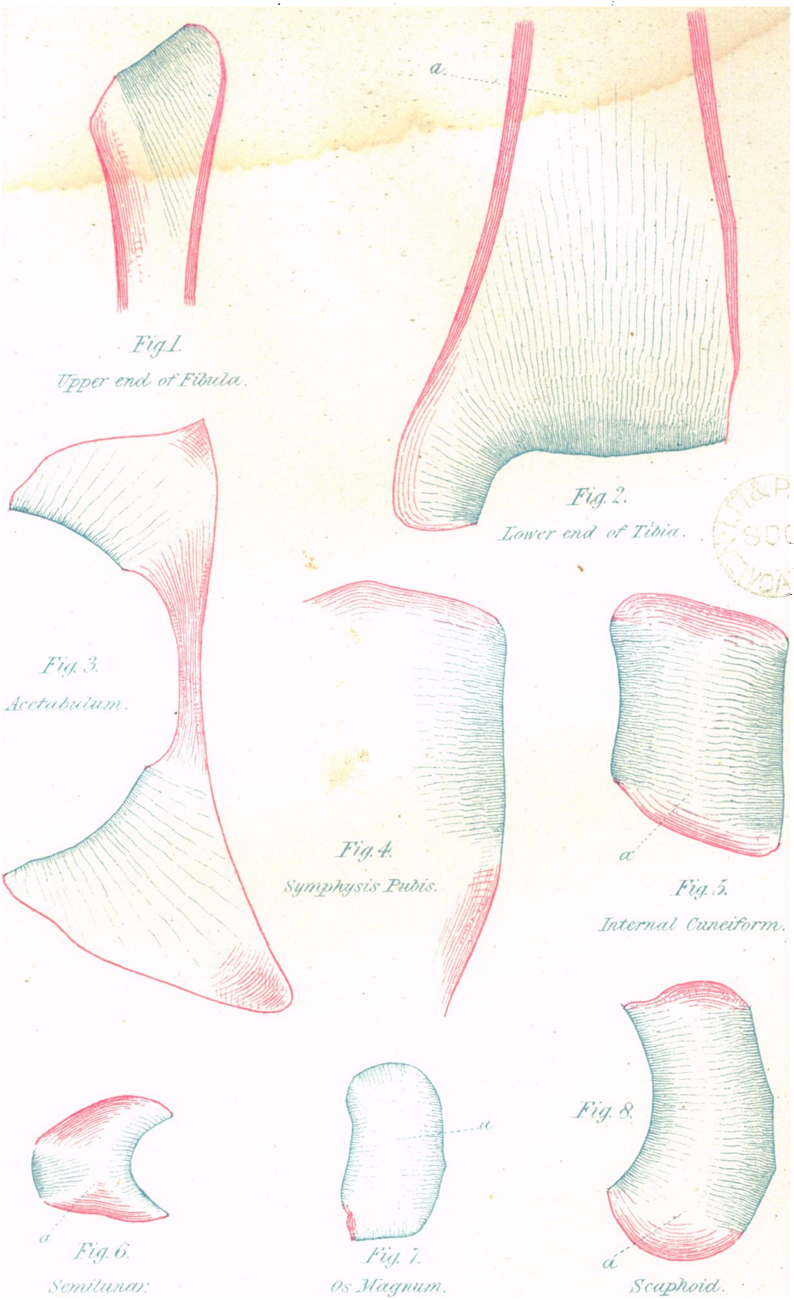
Fig. 2.

Lower end of Femur.

Periosteal bone, Red: Chondrogenous bone, Blue: a. Absorption spaces.



Periosteal bone, Red: Chondrogenous bone, Blue: a, Absorption spaces.



Periosteal bone,-Red: Chondrogenous bone, Blue: a. Absorption spaces.

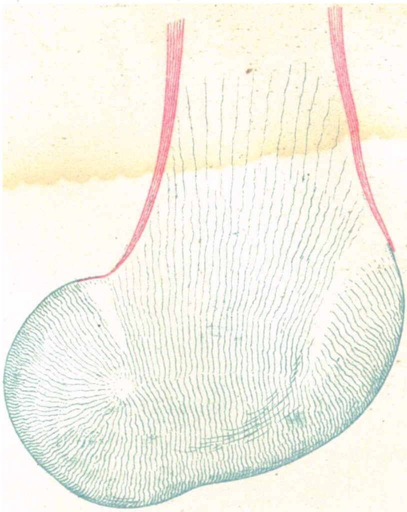


Fig. 1.

Sagittal Section of Condyle of Femur.

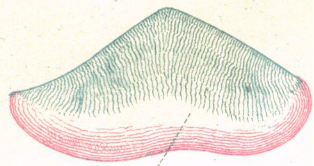


Fig. 2.

Patella. Horizontal Section.

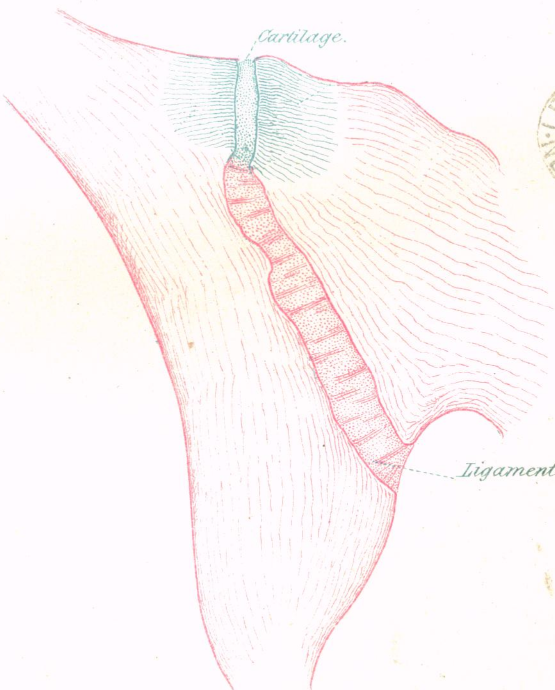
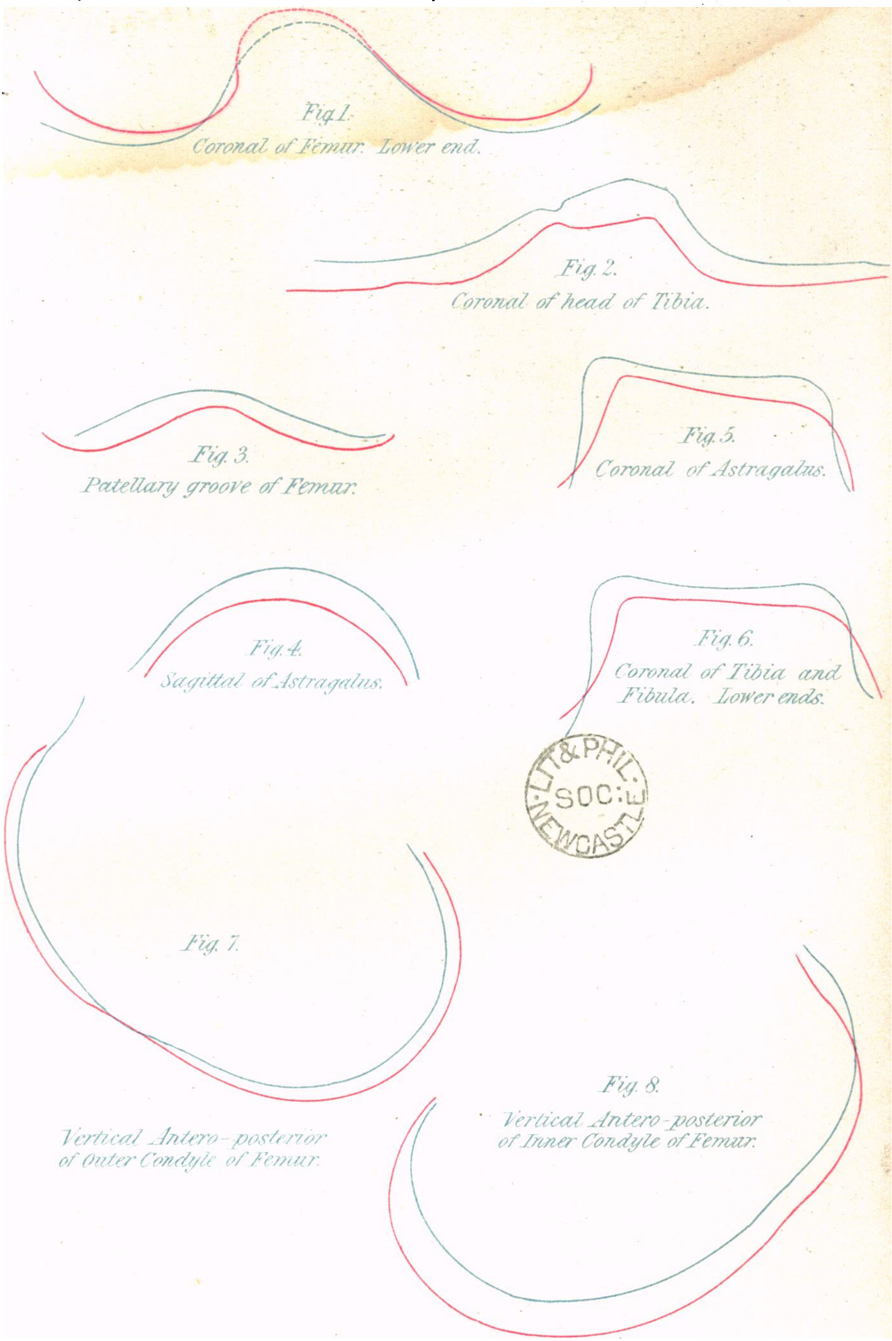


Fig. 3.

Section of Sacro-iliac Synchondrosis. (horizontal).

Periosteal bone, Red: Chondrogenous bone, Blue: a. Absorption space.



Surface curves of Joints. Adult curves, Red; Senile curves, Blue.

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EXPLANATION OF PLATES.

PLATE IX.—Difference between chondrogenous and periosteal osseous tissue. *a*, Chondrogenous bone. *b c*, Periosteal bone.

PLATE X.—Fig. 1. Vertical coronal section of head of tibia. Periosteal bone red; chondrogenous bone blue; absorption spaces, *a a a*. Fig. 2. Vertical sagittal section of astragalus. Periosteal bone red; chondrogenous bone blue; absorption spaces, *a*.

PLATE XI.—Fig. 1. Vertical sagittal section of astragalus. Periosteal bone red; chondrogenous bone blue; absorption spaces, *a a*. Fig. 2. Section of head and upper part of femur. Periosteal bone red; chondrogenous bone blue; absorption spaces, *a a a*.

PLATE XII.—Fig. 1. Horizontal section of head and neck of femur. Periosteal bone red; chondrogenous bone blue; absorption spaces, *a a*. Fig. 2. Vertical coronal section of lower end of femur. Periosteal bone red; chondrogenous bone blue; absorption spaces, *a a*.

PLATE XIII.—Periosteal bone red; chondrogenous bone blue; *a a*, absorption spaces. Fig. 1. Vertical section of anterior end of rib and costo-sternal cartilage. Fig. 2. Vertical coronal section of condyle of lower jaw. Fig. 3. Vertical sagittal section of dorsal vertebra. Fig. 4. Vertical coronal section of upper part of humerus. Fig. 5. Vertical coronal section of lower end of humerus. Fig. 6. Section through angle of scapula. Fig. 7. Vertical coronal section of glenoid cavity of scapula.

PLATE XIV.—Periosteal bone red; chondrogenous bone blue; *a a*, absorption spaces. Fig. 1. Vertical coronal section of upper end of fibula. Fig. 2. Vertical coronal section of lower end of tibia. Fig. 3. Section through acetabulum. Fig. 4. Vertical coronal section of symphysis pubis. Fig. 5. Section of internal cuneiform bone of tarsus. Fig. 6. Section of semilunar bone of carpus. Fig 7. Section of os magnum of carpus. Fig. 8. Section of scaphoid bone of tarsus.

PLATE XV. Periosteal bone red; chondrogenous bone blue; absorption space, *a*. Fig. 1. Vertical sagittal section of condyle of femur. Fig. 2. Horizontal section of patella. Fig. 3. Horizontal section of sacro-iliac synchondrosis.

PLATE XVI.—Surface curves of adult and senile articular facets contrasted. Adult curves red; senile curves blue. Fig. 1. Coronal curves of lower end of femur. Fig. 2. Coronal curves of upper end of tibia. Fig. 3. Horizontal curves of patellary groove of femur. Fig. 4. Sagittal curves of astragalus. Fig. 5. Coronal curves of astragalus. Fig. 6. Coronal curves of lower ends of tibia and fibula. Fig. 7. Vertical antero-posterior curves of outer condyle of femur. Fig. 8. Vertical antero-posterior curves of internal condyle of femur.