ON THE

MECHANICAL STRUCTURE

OF THE

CANCELLOUS TISSUE OF BONE.

BY

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ASSISTANT SURGEON, AND LECTURER ON ANATOMY, ST. THOMAS'S HOSPITAL.

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CANCELLOUS TISSUE OF BONE.

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In lecturing upon the human skeleton the importance of animal mechanics has struck me so strongly that I have been led to inquire a little more closely into certain points in connection with this subject, and I propose in this short paper to give the result of some observations made during the last two years upon the mechanical structure of the apparently indefinite spongy ends of bones.

We are accustomed to point out some of the mechanical apparatus found in the body, and especially the employment of the levers, and here and there the pulley. The third of the mechanical powers, the inclined plane, has been credited with not being represented in the human skeleton, but this is either an oversight or an error. For the sacrum is in principle a wedge or double-inclined plane, just as a common nail is; the large number of oblique articulations, such as are found in the carpus, tarsus, the sacro-lumbar and the spinal articulations, must also be ranked among the same class of mechanical arrangements. With reference

12

to the practical use of the wedge, it has been urged that "its great advantage appears to depend upon the percussion used to urge it into the mass of timber, &c., exciting vibration between the particles of the solid, and thus permitting the edge to insinuate itself between them. Certainly the direct action of a weight pressing upon the back of the wedge can bear no comparison with the immensely greater effect gained by percussion. The amount of weight necessary to *press* a common nail into a board, compared with the weight of a hammer that will readily *drive* it, is almost incredible." Now, it is just this steady pressure that the sacrum receives and that the pelvic ligaments are able to withstand, but it is rare indeed that it is subject to percussion, for the violence of shock in jumping and in active movements is broken in a variety of ways. Moreover, the sacrum is so curiously shaped as to lock the bones firmly together at the same time as the general arrangement is that of a wedge.

The mechanical advantages of bones are to be seen chiefly in their shape, their curves, ridges, spiral lines, and mouldings, all of which increase their strength and elasticity, while as levers nearly all the bones are placed at a disadvantage so far as regards the power used; but what they lose in power they gain in freedom and extent of movement.

The ends of the long bones are in nearly all cases enlarged for the purpose of providing attachment of muscles so as to bring the acting point of the power as near as possible to the fulcrum, or else for the purpose of giving steadier play to the joint; and it is here that we can trace a curious and wonderful adaptation of mechanics certainly surpassing in its ingenuity, simpleness, and efficacy, any of the most wonderful products of human skill. Strength, lightness, and elasticity are here combined in perfection, and the seemingly structureless mass of spongy bone is constructed so as to withstand the constant shocks from various directions to which joints are liable in the almost endless movements of the body. Some notice of this has been customary in referring to the neck of the thigh bone and the head of the tibia, and rough, though very imperfect, resemblances have been shown between the architectural arrangement in these parts, and simple mechanical structures like the bracket and gothic arch; but the hitherto-given descriptions are both incomplete and faulty, and the object of this paper is to show that in all cancellous tissues there is a definite mechanical arrangement, insuring the greatest strength and elasticity along the lines of greatest pressure.

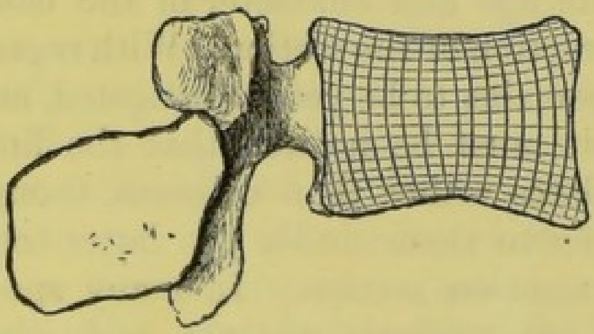
It is an interesting question to determine how far this mechanical arrangement is the result of conditions present in the living skeleton—how far, in fact, the architecture is the result of, rather than a provision for, pressure in certain directions. Doubtless intimate structure may be hereditary, but it seems more than probable that during the deposit of bony matter in the cartilaginous temporary structure its determination in certain lines is influenced by pressure and other known physical forces.

The lines seen in various sections differ in clearness of delineation according to the age and character of the bone, and also according to the direction of the section. With regard to the former point much remains to be yet investigated, and with regard to the latter it must be noticed that the lines indicate the existence of plates rather than columns, though it is more convenient to refer to them under the latter term since that is their appearance on section. In many specimens I possess the plates are perfectly distinct, and when these are cut obliquely their distinctness is necessarily lost.

The following observations were made without reference at first to those which I have since found in foreign works, and which have not been sufficiently noticed by English anatomists. In 1867 G. H. Meyer published in 'Reichert's Archives' a paper on the architecture of the cancellous tissue of the lower extremity. This was followed by a paper in 'Virchow's Archives' (1870), by Julius Wolff, chiefly upon the structure of the neck of the femur, and by Merkel in the same archives (1874); other papers are to be seen by Wolferman in 'Reichert's Archives' (1872), and by Aeby in the 'Centralblatt' (1873), and one more recently by Langerhaus in 'Virchow's Archives' (1874), dealing with the spine and upper extremity. The results, however, of my own observations differ in many material points from some of the foregoing, and for this reason, as well as for the purpose of bringing the subject before English anatomists, I have thought it advisable to publish them.

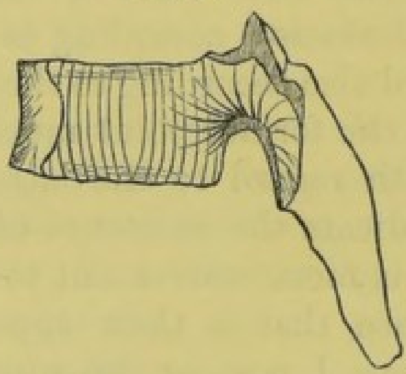
Spine.—If a vertical section be made through the body of a vertebra from before backwards it will be seen that the bony fibres of the cancellous tissue are arranged in two directions, vertically and horizontally. In the accompanying diagram (Fig. 1) the vertical fibres are shown not to be rectilinear but curved, and to have their concavity directed towards the centre of the bone. They therefore do not correspond with the outline of the surface which has its concavity looking in the opposite direction. Langerhaus depicts them as perfectly vertical lines, but this is certainly incorrect, and the advantage gained by curved lines is

FIG. 1.



Vertical median section of the body of a last dorsal vertebra.

FIG. 2.



Showing an arrangement in pedicle and body of dorsal vertebra.

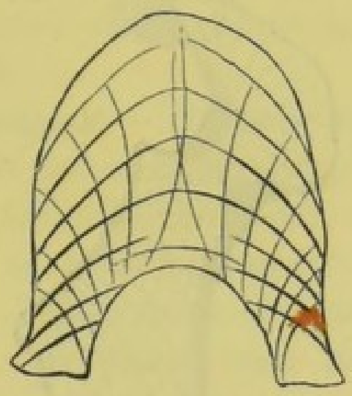
obvious in securing elasticity with equal strength. This accords curiously with an observation of Mr. Ward's that it has been found that wheels whose spokes are slightly curved possess far greater durability and power of resistance than those with straight spokes.

The horizontal fibres are slightly curved parallel with the upper and lower surfaces, and therefore with their convexities towards the interior of the bone. They are best marked towards the surface, and are not so well defined as the vertical set, and in the diagram are rather too clearly indicated in the centre.

If a vertical section be made through body and lamina (Fig. 2) it will be seen that a number of curves spring from the lower edge of the lamina and radiate into the body, and towards the articular process, where they end perpendicularly to the surface of pressure. The thick lower edge of the lamina here forms the supporting arch of the buttress.

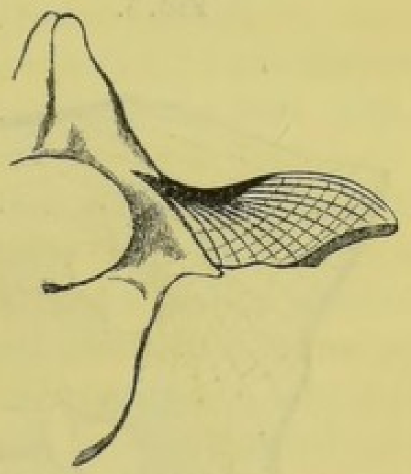
A horizontal section (Fig. 3) shows a porous tissue in which definite arrangement is somewhat difficult to make out, but in the pedicles arching fibres can be traced springing from each wall and spreading into the body of the bone, as a series of divergent curves which by their interlacement form the honeycombed interior.

FIG. 3.



Plan of arrangement in horizontal section of a vertebra.

FIG. 4.



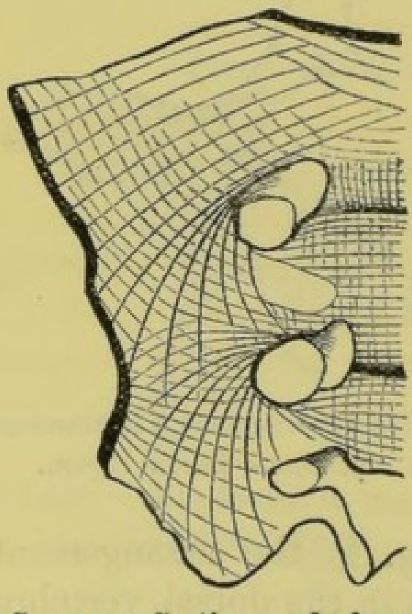
Plan of arrangement in transverse process.—Dorsal region.

In the transverse processes (Fig. 4) the arrangement is clearly defined when the process, as in the dorsal vertebræ, is large and the points of pressure evident. Fibres spring from the thick posterior wall at the root, and spread again in divergent curves, impinging perpendicularly upon the articular surface of the rib. Another set of curved fibres cross these at nearly right angles.

These crossing curves seen in the different sections are tied together so as to produce a marvellous contrivance, simple in structure, but of extreme strength, and it must be noticed that the arches spring usually from the strongest parts of the bone.

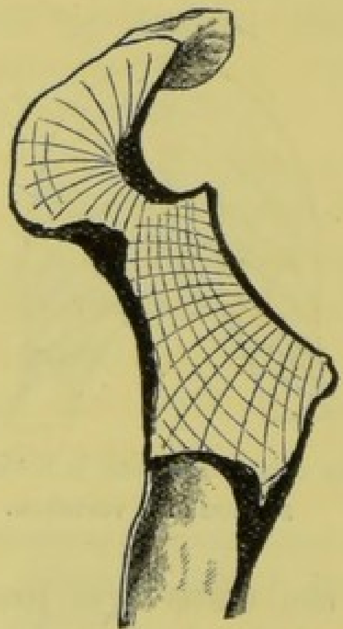
Sacrum.—In this compound of numerous vertebræ we trace out an arrangement of structure specially adapted for the pressure to which it is subjected from above and at the side. In a vertical section from side to side (Fig. 5) we notice, first, a more or less vertically directed set of fibres in the bodies, not truly vertical as Langerhaus depicts them, but slightly curved, having their concavities towards the middle line; secondly, a set running from the upper surface obliquely outwards to the iliac articulation, and curving more and more downwards as they pass and spring from the upper edge of the first sacral foramen until they run nearly vertically to the second foramen; thirdly, a set curving downwards from the second (and other similar ones probably from the other foraminia) and impinging partly upon the outer, partly upon

FIG. 5.



Sacrum.—Section made from side to side vertically.

FIG. 6.



Section of scapula through coracoid process and glenoid cavity.

the lower, surfaces; fourthly, a set running at first parallel with the iliac articular surface and curving inwards below; fifthly, a small but distinct series running from the lower part of the same surface and diverging as they pass inwards.

In these arrangements we cannot but recognise a wonderful provision for strength and elasticity, and particularly for protection against the pressure which comes from above and from the sides.

Langerhaus, again, appears to have fallen into the error of making the structure composed of straight lines, and thereby to have deprived it of one of the most important elements of construction, whether destined for strength or protection.

Clavicle.—In the ends of this bone the arrangement is not well defined, but it appears to partake of the same nature as found in other cancellous tissues, the network being composed of interlacing divergent curves.

Scapula.—A vertical section through glenoid cavity and coracoid process shows the following arrangement (Fig. 6): Fibres spring from the glenoid surface at right angles,[1] and diverge with their concavities downwards; other fibres run parallel with the surface. Another set springs from the thick front edge of the root of the coracoid process, and diverge as they curve backwards; these are crossed by a smaller set, best seen towards the posterior surface.

By these arrangements all pressure is received upon the ends of curved elastic fibres in whatever position the arm may be placed.

Humerus.—The construction of the cancellous tissue of the head is remarkably simple and effective (Fig. 7). From the thick walls of the shaft, which act as stems to the arms of a buttress, there spring two sets of curved fibres, one from each side. Those from the inner side are traceable in two directions; the lower ones interlacing with a well-marked series which spring from the outer wall and helping to form a beautiful gothic arch, the upper ones gradually curving in the opposite direction and terminating vertically upon the articular surface. From the outer wall the lowermost ribs of fibres have been already referred to as helping to form a gothic arch, but it must be noticed that some of them appear to pass on to the lower part of the glenoid surface, and here end vertically; the uppermost fibres are slightly curved with their concavity outwards, but are nearly vertical, and end on the upper surface of the great tuberosity. Langerhaus's description differs much from this, as he makes the bone to be composed of straight ribs, vertical and oblique, except towards the lower part of the articular surface, where his observation accords with that here given.

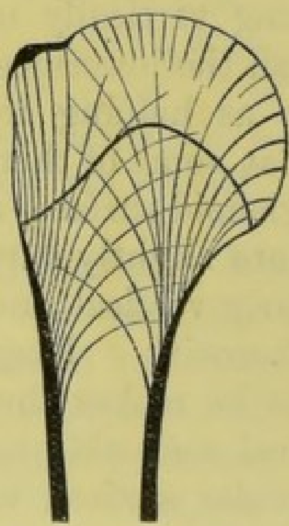
The curves formed by the fibres I have described appear to be true parabolic curves, and this is hardly indicated with sufficient clearness in the Figure. It has been suggested to me by Dr. Stone—for whose opinion in such matters I have

[1] This is not accurately delineated in the upper part of the diagram.

the greatest respect—that it would be interesting to trace mathematically the relation between the curve of the parabola and that of the articular surface.

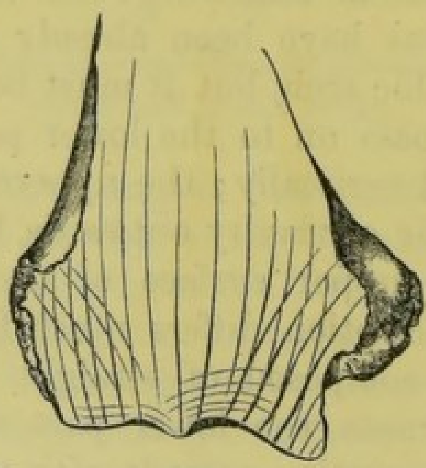
In noticing the effect of this arrangement it must be borne in mind that pressure is exerted against the humerus from two surfaces—the articular, and the upper aspect of the great tuberosity. That occurring at the glenoid surface varies in direction according to the position of the arm, and consequently we find the bony fibres so arranged as to impinge vertically upon all points of the surface, so that in whatever position the limb is placed some fibres receive the force vertically, and by their curve diminish it before it reaches the shaft. The other joint through which pressure comes is one frequently overlooked. It is that between the great tuberosity and the coraco-acromial ligament, and is brought into action whenever the weight of the body is supported vertically by the hands, as in resting with the hands upon a table, or leaning upon the elbows, or in raising oneself from a chair by means of the hands placed upon the arms of it. The columns or fibres which run in the tuberosity are, therefore, arranged nearly vertically, and are not dispersed as in the case of the head of the bone.

FIG. 7.



Plan of arrangement seen in head of humerus.

FIG. 8.



Lower end of humerus. Section from side to side vertically.

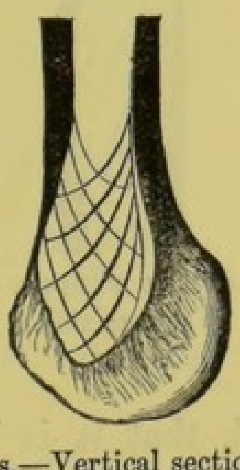
It will be seen in the diagram that the line of epiphysis does not interfere with the arrangement of the fibres.

If the structure of this part be compared with that of the head of the femur a curious identity of principle will be noticed. In each case divergent curves spring from their shaft on opposite sides, interlace to form a series of gothic arches and end with evident effect or design vertically upon the parts through which pressure is to come.

In the lower end of the humerus (Fig. 8), the principle of construction is somewhat complicated, owing to the shape of the joint surface. From the walls of the shaft curved fibres run across to the opposite side with their concavities towards the middle line of the bone, so as to produce by their interlacement a series of inverted pointed arches in the lower end of the shaft; these are in some specimens very distinct. The mass of the cancellous tissue is composed of columns which pass downwards from the spreading buttresses of the shaft, and curve with their concavity towards the middle line of the bone, so as to impinge at length vertically upon the articular surfaces below. Some enter the condyles and are here arranged with less distinctness. A set is visible running parallel with the articular surfaces, and two other sets are traceable, but less distinctly, one in each lateral half, and crossing those of each condyle obliquely.

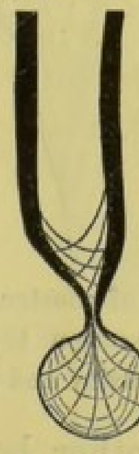
If now a section be made through one of the condyles vertically from before backwards (Fig. 9), the arrangement is

FIG. 9.



Humerus.—Vertical section through trochlea on inner condyle.

FIG. 10.



Humerus.—Vertical section through middle line between olecranon and coronoid fossæ.

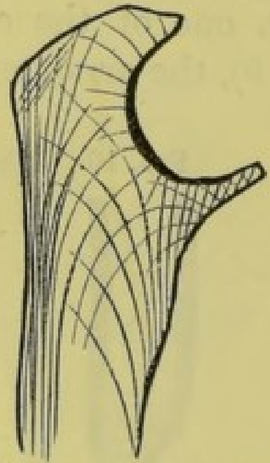
seen to be simple, and to consist of two sets of curved fibres diverging as they pass downwards, interlacing, and terminating vertically to both anterior and posterior articular surfaces. These curves are parabolic.

A similar section in the middle line (Fig. 10) shows a curiously different construction. In the lower end of the shaft the old arrangement exists, but the articular portion which is here nearly circular, shows curved fibres springing from the lamina between the two fossæ, and curving backwards and forwards respectively to the posterior and anterior aspects, so as to terminate at right angles to these surfaces. Other fibres are placed more or less concentrically with the outline of the section.

These simple and beautiful arrangements are admirably adapted to protect the bone from concussion in every position of this exposed and constantly used joint.

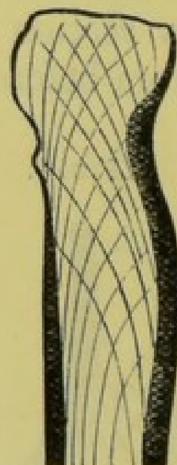
Ulna.—The shape of this bone being peculiar and evidently intended for special mechanical purposes, the arrangement of its internal structure becomes of considerable importance. In a vertical section of the upper end from before backwards (Fig. 11), we are able to see that the same principle is carried

Fig. 11.



Ulna.—Plan of construction seen in vertical section through great sigmoid cavity and olecranon.

Fig. 12.



Ulna.—Section of upper end from side to side.

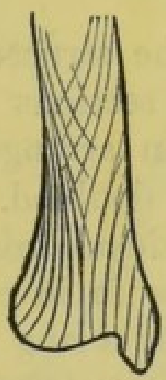
out as in other bones already noticed, that it is built up essentially of curved columns more and more diverging, and that the uppermost of these are concerned in the support of pressure at the joint surface. Those springing from the front wall of the shaft receive the pressure which occurs when the arm is extended as in striking "from the shoulder," or in pressing with the arms straight; those springing from the back wall of the shaft impinge upon the middle of the articular surface in part, but part run into the olecranon, and so would receive the pressure acting through the length of the bone when the arm is bent and the elbow rests on the table.

In a section of the same part (Fig. 12) from side to side we see a somewhat similar arrangement of crossing parabolic curves forming arches more and more pointed as they are traced upwards. There does not appear to be any clearly defined arrangement in connection with the lesser sigmoid cavity, and from this it is evident that very little pressure occurs between the two bones at this joint.

In examining a simple transverse section through the head, the curved columns are again found to be in relation with the articular surface for the humerus and not for the radius; they impinge vertically upon the former surface.

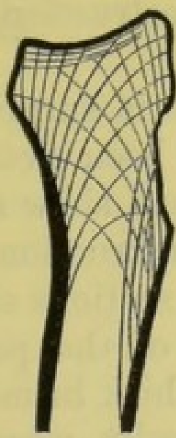
At the lower end (Fig. 13) the arrangement consists of two sets of divergent curves, one of which ends upon the lower articular surface which presses upon the triangular ligament, and the other set runs into the styloid process.

Fig. 13.



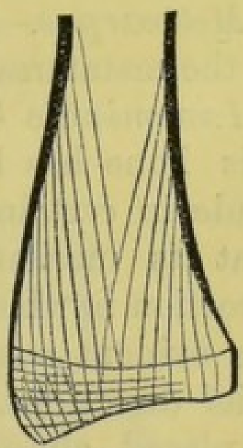
Ulna, lower end.—Vertical section through styloid process.

Fig. 14.



Radius.—Arrangement seen in head, neck, and tubercle.

Fig. 15.



Radius, lower end.—Vertical section from side to side.

When a transverse section is made through this end the main direction of the fibres is found to be parallel with the articular surface, and not impinging upon it—another evidence of this absence of much pressure at the articulation.

Radius.—The upper end (Fig. 14) shows an arrangement of crossing divergent parabolic curves which spring from both sides of the neck and shaft, and the uppermost end perpendicularly to the surface. In the tubercle the fibres run as a nearly vertical set, curved slightly, however, with their concavity towards the tubercle.

In the lower end (Fig. 15) we find two main sets of vertical fibres springing one from each side of the shaft, and ending vertically to the articular surface below. Other fibres run nearly horizontally, but none are found to end with any distinctness upon the surface of the sigmoid cavity.

If a transverse section be made of the head or neck the arrangement is indefinite, but a section through the tubercle shows two chief sets of fibres, one springing from the point of insertion of the biceps, diverging and curving with their concavities backwards; another starting from the anterior and outer aspect of the bone, and curving across the former with their concavities directed inwards.

At the lower end the fibres are arranged in two directions, one mainly from before backwards, the other parallel with the anterior and posterior margins.

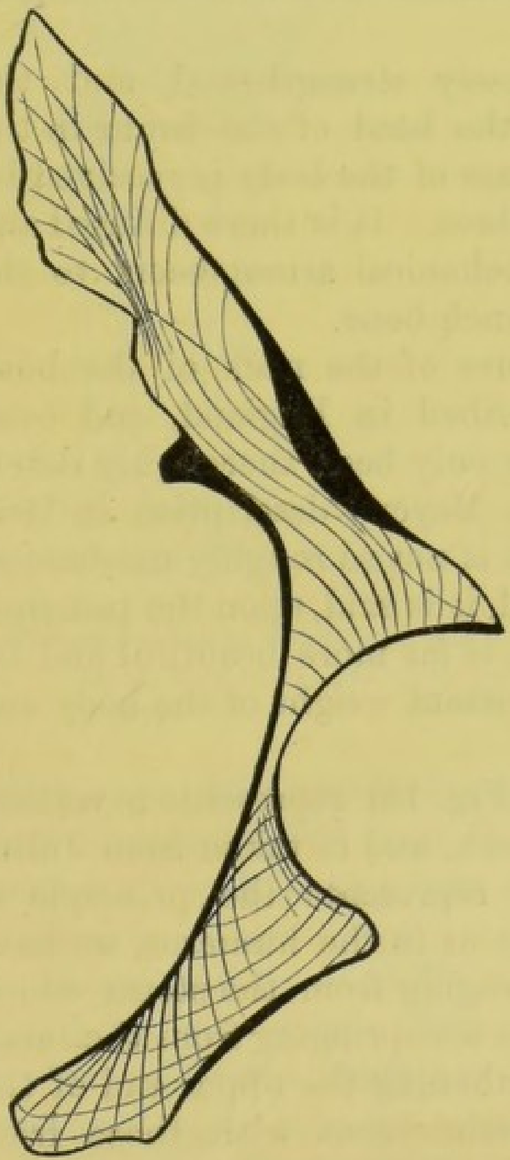
Carpus.—I have not been able yet to satisfy myself of the principle of arrangement here.

Metacarpus.—The construction is identical with that seen in the metatarsal bones.

Innominate bone.—It is surprising that the structure of this bone has hitherto been overlooked, for sections when made in certain directions show so definite an arrangement that its mechanical construction cannot be doubted. The direction in which these sections should be made accords with the evident adaptation of the pelvis to pressure in certain chief directions. The thick brim forms part of a ring which is placed almost vertically when the body is erect, and transmits the weight of the body to the lower extremities; but by its shape it ensures a wonderful amount of strength, elasticity, and protection. It is along the line of this ring that we must look for evidence of mechanical construction in the porous bone. Again, when the body is in the sitting posture the tuberosities of the ischia receive the pressure, and if we examine the external configuration of the innominate bone, we notice that a thick rib of bone extends upwards from the tuberosity to the anterior superior spine. It is along this line that pressure is exerted vertically, and it is along this line that we find the internal arrangement definite.

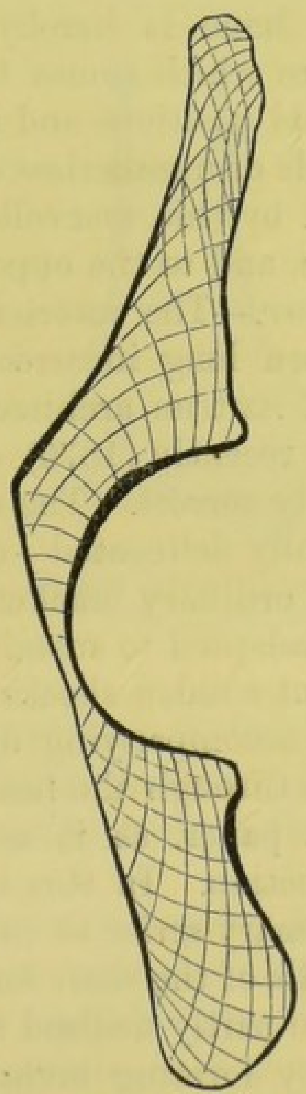
In a section extending from pubis to sacro-iliac synchondrosis through the acetabulum and along the brim of the true pelvis (Fig. 16), we see tracing from before backwards that the part in front of the acetabulum (*i. e.*, body of pubes), is made up of two sets of divergent curves which spring from opposite sides, and

Fig. 16.



Section of innominate bone horizontally from pubes to sacro-iliac joint.

Fig. 17.



Innominate.—Vertical section from anterior superior spine to tuberosity.

cross one another: some of these are traceable as continuous with certain fibres which start perpendicularly from the articular surface. Behind the acetabulum ,other curved fibres run from this surface backwards, and form apparently sinuous lines, which may, however, result from opposite curves springing from the outer and inner surfaces of the bone.

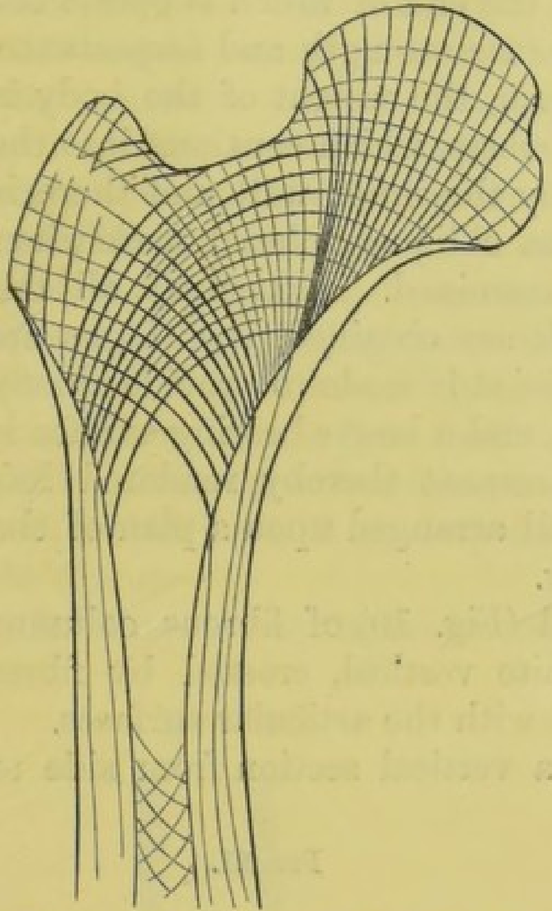
In a vertical section from anterior superior spine to the tuberosity of the ischium (Fig. 17), there is a somewhat similar arrangement. One set of parabolic curves radiate from the articular surface of the acetabulum, and those in the upper and lower parts of the section are crossed by other curves, so as to form a very distinct interlacement, and in the lower part very evident inverted arches.

The bone is hereby immensely strengthened, and the pressure which comes through the head of the femur in the manifold positions and movements of the body is received by the ends of numberless curved fibres. It is there diffused and carried by this marvellously mechanical arrangement to the sacrum, and to the opposite haunch bone.

Femur.—The internal structure of the neck of the bone has been long incorrectly described in England, and even abroad its true architecture has only been thoroughly determined recently (1870), although Meyer's description in 1867 is nearly correct. The structure is not so roughly mechanical as usually delineated—composed, it is said, upon the principle of the ordinary bracket—but it is far more beautiful and far better adapted to sustain the constant weight of the body and frequent sudden shocks.

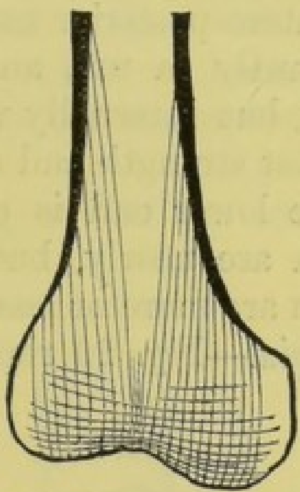
The accompanying diagram (Fig. 18) represents a vertical section through the head and neck, and is taken from Julius Wolff's paper, as it accurately represents the principle of construction. In this bone, just as in the humerus, we have the primary series of curves springing from the stems which the walls of the shaft form. The set springing from the inner wall are partly utilized in strengthening the upper end of the shaft by forming arches of interlacement with those from the outer wall; the uppermost fibres run into the head and end upon the articular surface in such a manner as to oppose the usual direction of pressure, while the intermediate fibres are less definite and form the cancellous tissue of the neck. All these, however, belong to one continuous series of increasingly divergent curves, and it must be noticed that those which enter into the head do not spread so thoroughly as in the case of the head of the humerus. This is accounted

Fig. 18.



Femur.—Plan of construction in head, neck, trochanter, and upper part of shaft.

Fig. 19.



Femur, lower end.—Section from side to side.

for by the difference in freedom of movement at the shoulder and hip-joints, the head of the humerus receiving pressure perpendicularly to any part of its articular surface, the femur only over a limited area.

The second series of fibrous columns which spring from the outer wall are chiefly concerned in the strengthening of the upper end of the shaft, but some are traceable onwards into the head, and these are more or less parallel with the surface which ordinarily receives pressure.

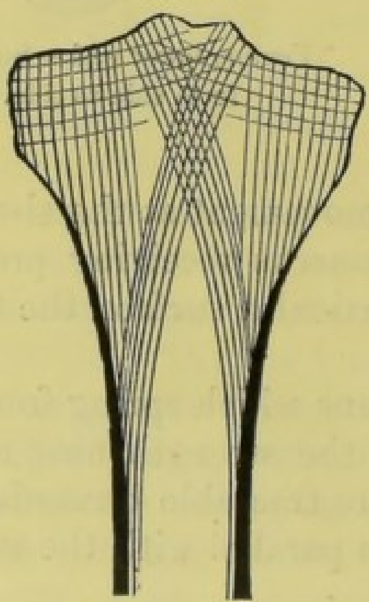
A few fibres run into the great trochanter, but they are comparatively indefinite, and herein they differ from those in the great tuberosity of the humerus. The reason, however, is obvious. There is no vertical pressure over this part, and no joint above it as there was in the case of the humerus.

There is one point in regard to the mechanical structure of the femur which is seen in this section, and has been, I think, entirely overlooked. The inner wall of the neck and shaft form a continuous curve, the end of which supports the head, and this curve is of immense strength and importance. As will be seen by the diagram, the weight of the body is received by the ends of curved fibres, which continue into the curve of the buttress formed by the inner wall, and there is no such arrangement seen as an obliquely placed neck when the internal construction is examined. Externally all the advantages of an oblique neck are obtained, the thighs are separated, the ball and socket-joint is made to provide chiefly for antero-posterior movement, and a larger bearing surface is constantly in use, and displacement thereby rendered less liable, but internally we find all arranged upon a plan of the greatest strength and elasticity.

The lower end is composed (Fig. 19) of fibrous columns which are nearly, but not quite vertical, crossed by fibres which are more or less parallel with the articular surfaces.

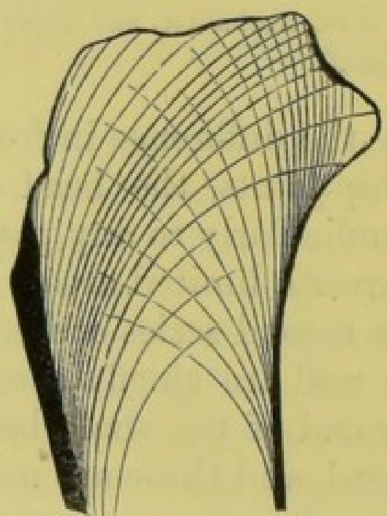
Tibia.—Fig. 20 represents a vertical section from side to

FIG. 20.



Tibia.—Vertical section of upper end from side to side.

FIG. 21.



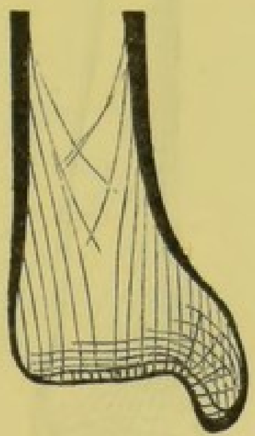
Tibia.—Arrangement seen in antero-posterior section.

side through the head of the bone, and is drawn somewhat more diagrammatically than most of the others. The principle of construction appears to be—1, a set of nearly vertical fibres in each lateral mass curving slightly with their concavities towards the middle line; 2, a set of fibres crossing these nearly at right angles, being parallel with the articular surfaces and arranged near them; 3, a set springing from the shaft on each side, and ending upon the rising sides of the spine; these by their interlacement form well-marked arches, which are continued for some distance down the shaft.

A different arrangement is seen when the section is carried from before backwards in the middle line (Fig. 21). The arches spring from opposite sides as a series of increasingly divergent curves, of which those passing from the front are, on the whole, the best marked, and end behind the spine. Of the other fibres springing from the posterior wall those are best marked which run upwards to support the pressure of the femur.

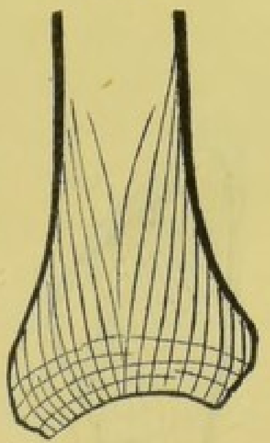
Looking now at the lower end (Fig. 22) we find the arrangement nearly the same in whatever direction the section be made. The fibrous columns are nearly vertical but slightly curved, and in the malleolus they spread as divergent curves from the articular surface, so that here, as in the other fixed bones, the construction is such that the weight is taken by fibrous columns starting perpendicularly to the surface of pressure. It is worthy of notice that no definite arrangement is visible as springing from the articular surface for the fibula

Fig. 22.



Tibia, lower end.—Section including malleolus.

Fig. 23.



Tibia, lower end.—Vertical section from before backwards.

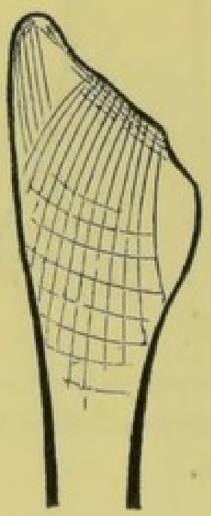
at this end, and this is an evidence of the absence of pressure at this articulation.

Fig. 23 represents a section from before backwards.

There is not infrequently in the shafts of long bones a curious construction whose cause and meaning it is difficult to understand. One or more porous plates are stretched across the medullary cavity at irregular intervals, and there is in the museum of St. Thomas's Hospital a specimen of extremely atrophied tibia in which only few of the bony columns are left, but these porous septa remain curiously evident.

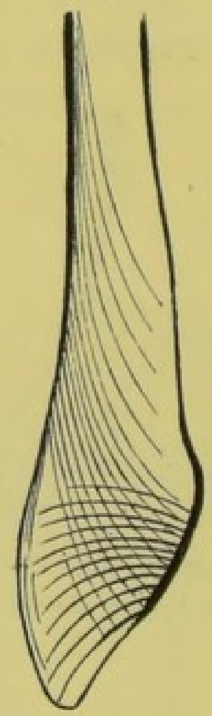
Fibula.—The structure of this bone throws some light upon its functions in the human skeleton, and helps to show that a certain amount of the vertical pressure of the body acts through the fibula. A section through the upper end (Fig. 24) shows in the better-marked specimens an arrangement of curved fibres extending from the articular surface

FIG. 24.



Fibula: head.—The chief curved lines end on the articular surface for the tibia.

FIG. 25.



Fibula.—Lower end.

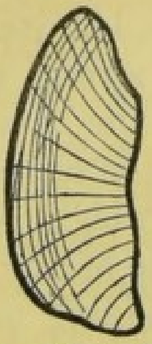
and spreading into the shaft, where they are crossed by other curved fibres nearly transversely. A few run separately into the styloid process and are nearly vertical. Now, in the majority of bones the arrangement is difficult to trace clearly, and beyond the portions marked in the diagram the cancellous tissue is simply porous and indefinite. Still the presence of these curved fibres is very strong evidence of pressure being exerted in the long axis of the bone, and when the position of the fibula with regard to the outer condyle is noticed it becomes more certain that the weight of the body, when carried through the external condyle of the femur and outer tuberosity of the tibia (as in standing on one leg), must be in part carried to the fibula. Perhaps it will be more evident if the force be traced from below, when the fibula receives part of the upward force from the astragalus, for the same pressure which separates the malleoli when a man is jumping or bearing a great weight also forces the fibula upwards. A further evidence of the association of tibia and fibula for this direction of pressure is to be found in the fact that special diverging plates or fibres are seen in the tibia springing from the articular surface against which the fibula lies.

At the lower end (Fig. 25) diverging curves start from the surface of pressure—from that surface which comes into contact with the astragalus, and these are crossed by other less distinct curves at varying angles. Now, it is noticeable here that, although the fibula is in contact with the tibia, and is somewhat thick in its shell at that point, no columns are seen in relation to that surface. Moreover, none are visible in the corresponding portion of the tibia. This must be taken in connection with the fact that little or no pressure is exerted between these two surfaces, and we then see another corroboration of the view that these curved fibres are directly related to the lines of greatest pressure. The lines here depicted differ somewhat from those drawn by Langerhaus, as will be seen on reference to his monograph.

Patella.—A vertical section (Fig. 26) shows (*a*) a set of curved fibres springing from the articular surface behind and diverging as they pass forwards to the front, and arranged so that they are at first vertical to the surface of pressure (*b*), curved lines parallel with both anterior and posterior surfaces, but best marked in front.

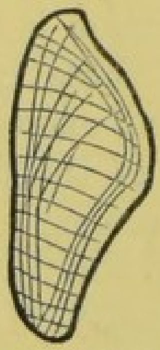
In a horizontal section (Fig. 27) those appearing parallel

FIG. 26.



Patella.—Vertical section.

FIG. 27.

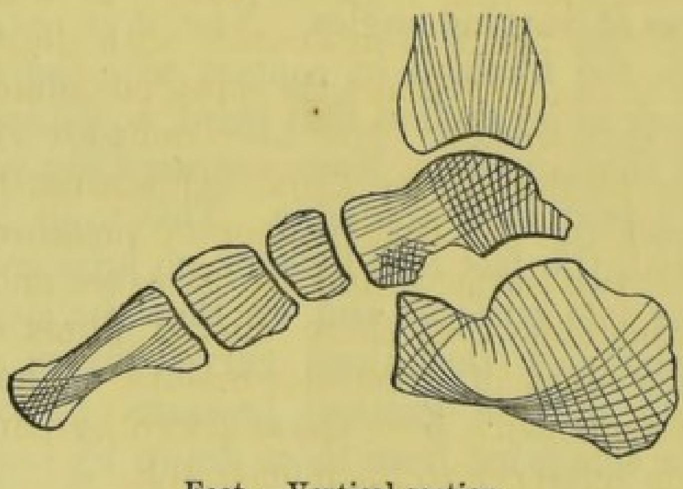


Patella.—Horizontal section.

with the anterior and posterior surfaces are best marked, but here the posterior set are best seen. Other fibres run across the substance of the bone in the manner indicated in the diagram.

Foot.—A vertical section through the foot shows in a remarkable way the adaptation of the mechanical structure of different bones to one another, the curved fibrous plates of one bone being continuous with those of the next. From the astragalus (Fig. 28) curved fibres are traceable forwards

FIG. 28.



Foot.—Vertical section.

which diverge in the scaphoid and internal cuneiform, and in the metatarsal bone completely separate into two sets, which, however, cross one another in the head of the bone. What more admirable arrangement could be devised to provide this long axis of the foot with strength and protection against the constant violence it is exposed to? It may be noticed that these curves are continuous with the posterior curves of the tibia. The anterior fibres of the tibia are traced differently. They are in a line with certain curves which pass between the upper and lower articular surfaces of the astragalus converging to the latter, and from the opposed surface of the os calcis spread in divergent curves into the heel. We have, therefore, in such a section (in which I have been able to confirm Meyer's observations), two main lines of curves indicating the two main lines of pressure; the anterior set concerned chiefly in those more violent actions which occur when the heel is raised, the posterior set in the support of steady pressure when the heel is on the grouud.

Another set of curves form a series of inverted arches, forcibly suggesting the similar arrangement seen in the masonry of buildings where a great weight of superstructure has to be borne. Other secondary sets cross some of these usually at right angles.

In other sections slightly different appearances are obtained, as, for instance, one towards the outer side of the foot in which the cuboid is seen to be composed of curved spines continuous with those of the front of the os calcis.

In transverse sections two similar continuous spreading curves are traceable from bone to bone, indicating the lines of greatest pressure, and always impinging upon the articular surfaces at right angles where the pressure is vertical to the surface.

These observations will be of interest not only to students of anatomy, but to those engaged in mechanics generally. No doubt, we have in the human skeleton many and varying directions in which force is applied, and therefore many requirements to meet in the construction of bones, but it seems to me that a study of the architecture of these parts points to an improvement of the construction of fixed structures, and that curved lines might with great advantage be made use of in preference to straight ones, as by their elasticity they ensure far greater stability.

A practical bearing of this question occurs in the direction of fracture from indirect violence both in the shaft and towards the ends of long bones. The solid substance of the shaft is constructed after exactly the same principle as the better-defined cancellous tissue, for in bones which have become atrophied from any cause a curvilinear fibrous arrangement is readily traceable in the shafts, and when bones are decalcified they can be torn along the same lines more readily than in other directions. Fractures of shafts from indirect violence are almost always oblique, and in looking over a large number of specimens in our museum I find that the obliquity of the fracture coincides with the obliquity of the curves seen in atrophied bones.

In the ossified callus which occurs about old united fractures there is also a definite arrangement of the bony fibres which compose it, and these fibres are placed in the direction of the greatest pressure.

In furtherance of this question I trust at some future time to examine the arrangement found in deformities and also in other classes of animals where the pressure is different in direction from that found in the human skeleton.

I must acknowledge here the kindness of Messrs. J. and A. Churchill in permitting me to make use of the foregoing engravings, which are intended for a manual of osteology shortly to be published by them.