Researches tending to prove the non-vascularity and the peculiar uniform mode of organization and nutrition of certain animal tissues : viz. articular cartilage, and the cartilage of the different classes of fibro-cartilage; the cornea, the crystalline lens, and the vitreous humour; and the epidermoid appendages / by Joseph Toynbee.

David Pollock Esq
with the kind regards of the Author

RESEARCHES,

TENDING TO PROVE

THE NON-VASCULARITY

AND THE PECULIAR UNIFORM

MODE OF ORGANIZATION AND NUTRITION

OF CERTAIN

ANIMAL TISSUES,

VIZ.

ARTICULAR CARTILAGE, AND THE CARTILAGE OF THE DIFFERENT CLASSES OF FIBRO-CARTILAGE; THE CORNEA, THE CRYSTALLINE LENS, AND THE VITREOUS HUMOUR; AND THE EPIDERMOID APPENDAGES.

BY

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1841.

XIII. *Researches, tending to prove the Non-vascularity and the peculiar uniform Mode of Organization and Nutrition of certain Animal Tissues, viz. Articular Cartilage, and the Cartilage of the different Classes of Fibro-Cartilage; the Cornea, the Crystalline Lens, and the Vitreous Humour; and the Epidermoid Appendages.* *By* Joseph Toynbee, *Esq., Member of the Royal College of Surgeons, London, and late Assistant to the Conservators of the Museum of that Institution. Communicated by Sir* Benjamin C. Brodie, *Bart. F.R.S. &c. &c.*

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Introduction.

It is now generally acknowledged that the process of nutrition in most animal tissues consists in changes undergone by the nutrient liquor sanguinis, which has exuded into them through the coats of the capillaries ramifying throughout them. The vessels themselves vary in number in different structures: in muscle, the capillaries are very numerous, and the spaces between them very small; whilst in tendon and ligament, on the other hand, the latter are comparatively large; but in all structures, whatever may be the degree of their vascularity, the tissue the furthest removed from the vessel is nourished equally well with that which is in immediate contact with it.

In all vascular structures, therefore, there is of necessity a considerable extent of tissue which is nourished without being in contact with blood-vessels, and the knowledge of this fact forms a necessary introduction to the study of the process of nutrition in those organs, into which, whilst in a healthy state, anatomists have never succeeded in tracing blood-vessels. The organized tissues, constituting such non-vascular organs, may be divided into three classes:

The first, comprehending articular cartilage, and the cartilage of the different classes of fibro-cartilage;

The second, the cornea, the crystalline lens, and the vitreous humour;

The third, the epidermoid appendages, viz. the epithelium, the epidermis, nails and claws, hoofs, hair and bristles, feathers, horn, and teeth.

It is to these tissues that the investigations I have now to communicate relate: I shall endeavour to prove that no vessel ever enters them when they are perfectly developed, and in a healthy state, and to demonstrate the manner in which they are nourished.

In the first place, no anatomist has ever been able to trace vessels into these tissues

in the adult healthy state; and it appears to me, that the due action of the organs into the composition of which these tissues enter is incompatible with vascularity; in other words, that the presence of blood-vessels within them is a sign of disease.

The first class, for instance, of the non-vascular tissues, comprising cartilage and fibro-cartilage, is subject, from its situation in the joints, &c., to repeated concussions, and to constant compression and attrition, which in these unyielding tissues would necessarily be destructive of the integrity of blood-vessels.

Those of the *second class* are required to be perfectly transparent for the due transmission of the rays of light, which would be impossible if the circulation of a coloured fluid were carried on throughout their substance*.

The tissues of the *third class* are unceasingly exposed to friction, laceration and incision; and hence, of course, it is necessary that they should not be traversed by vessels.

In the numerous attempts which I have made to inject these tissues, I have never been able to trace a blood-vessel into any one of them: on the contrary, my injections prove that the vessels which previous anatomists had traced no further than their circumference (supposing them to be continued into these tissues, either as serous vessels, or as red blood-vessels too minute for injection), actually terminate in veins, without the limits of these tissues. The terminations of these vessels in the immediate vicinity of the non-vascular tissues, present certain convolutions, dilatations, plexuses and other peculiarities, which differ in various parts, but in all instances enable a large quantity of blood to circulate slowly in the neighbourhood of these tissues, from which it may be inferred that they are subservient to the nutrition of the latter; and their existence certainly constitutes another argument against the presence of vessels within them.

All these non-vascular tissues are in structure very analogous: they all contain corpuscles or cells, of which some of them are almost entirely made up; while in others, as the cornea, a few only are present.

I am induced to ascribe to these corpuscles very important functions, and I shall therefore make a few observations upon them. Schleiden has lately concluded, from the researches which he has conducted, that all vegetable tissues are developed from cells. Schwann has arrived at similar conclusions on the mode of development of animal tissues, and he has proved, I think satisfactorily, that tissues which, when perfectly formed, have a structure so different from each other as articular cartilage and muscular fibre, are developed in a similar manner, viz. from cells. M. Schwann ascribes to these cells, during development, a vital function, and believes that they must have the power, not only of attracting, but also of chemically changing, the substances brought into contact with them†.

* I believe that the blood discs circulate through all vessels, and Müller allows that the existence of serous vessels (viz. those carrying the liquor sanguinis only) has never been demonstrated.

† The British and Foreign Medical Review, vol. ix. p. 523. It is to the very valuable article in this

To the elaborate researches of these physiologists, and to those of Müller, Valentin, Purkinje, Henle, &c., I must refer for information upon the nature and intimate structure of these corpuscles.

These cells are modifications of two principal forms, the one being either round or oval, the other compressed in the form of a scale; and their existence in one of these two forms has lately been detected in most organs of the body.

In a circular form they appear to be the principal components of bone, cartilage, muscular and nervous fibre, and of the parenchyma of glands*; in the form of a flattened cell or scale, they constitute the epidermis and its appendages, the epithelium of mucous and serous membranes, and of the inner tunic of the vascular system.

When the almost universal presence of these cells is considered, I think it cannot be doubted but that they perform important parts in the functions of nutrition and secretion.

I am induced to agree with M. Schwann, that these cells have vital actions, and I believe that they not only possess them in the tissues during development, but also in subsequent periods of life. I ascribe to them the function of circulating, and of perhaps changing the nature of, the nutrient fluid which is brought to the circumference of the solid non-vascular tissues, and I believe them in some measure to compensate for the absence of the internal vascularity possessed by other structures.

In proof that they possess vital properties, I may allude to the changes undergone in the structure of the cornea and the crystalline lens, without the penetration of them by any vessels.

I must here observe, that in some of the non-vascular tissues, as in the cornea and the vitreous humour, where only a small quantity of corpuscles exists, the laxity of their consistence admits of their ready penetration by the nutrient fluid brought to their circumference.

The only difference which appears to me to exist between the mode of nutrition in the vascular and the non-vascular animal tissues is, that *the former* derive their nutrient fluid from the blood which circulates through the capillaries contained in their substance; and that *the latter* are penetrated by the nutrient fluid which exudes from the large vessels by which they are surrounded, and that its distribution through them is assisted by the vital properties of the corpuscles which they contain; in *both classes*, the particles of which the tissues are composed attract from this fluid the elements which nourish them†.

Journal, and to some additional pages by Dr. Baly, in the second edition of his Translation of Müller's Elements of Physiology, that I am indebted for my knowledge of Schwann's and Schleiden's labours.

* Valentin and Purkinje.

† In reference to this subject, I beg to direct particular attention to the following quotation from Professor

The First Class of Non-vascular Animal Tissues.

Of Articular Cartilage and Fibro-Cartilage.

The tissues which I have placed in the first class are articular cartilage, and fibro-cartilage; but in reference to the latter, the cartilaginous portion only can be considered as non-vascular. These tissues are analogous to each other in their situation, structure, mode of nutrition and functions. Each of them forms a part of joints, and is subject, in the performance of its functions, to concussion and compression, and is composed of corpuscles or cells possessing similar characters. Although they are properly considered as non-vascular tissues, they appear to be pervaded by blood-vessels at an early period of their development, or perhaps it would be more correct to say, that as growth proceeds, the cartilage increases, so as to occupy the space which had previously been permeated by vessels.

I have been able to demonstrate that vessels are never found within these cartilages when fully developed, but at that period vessels form convolutions in their immediate vicinity. These vessels are separated from articular cartilage at adult age by a layer of bone, and in fibro-cartilage, at the same period, they uniformly terminate within the boundary of its fibrous tissue. Over a certain portion of the free surface of both of these tissues blood-vessels extend, but they do not penetrate into their substance.

The investigations which are about to be detailed, lead, I think, to the certain conclusion, that articular cartilage in the adult state is principally nourished by fluid derived from the vessels of the cancelli of the bone to which it is attached, which exudes through the coats of those vessels, and makes its way into the substance of the cartilage through the intermediate lamella of bone. The cartilage of fibro-cartilage is nourished in like manner by liquor sanguinis, derived from vessels situated in the contiguous fibrous portion. The vessels ramifying in a certain extent of the free synovial surface of both these species of cartilage contribute doubtless to their nutrition, but not to near the same extent as do the vessels of the opposite side. With respect to the actual process of nutrition in these cartilages, I shall only observe here, that the cells of these structures must be regarded as having the function which has been ascribed to those of all non-vascular tissues, viz. that of promoting the circulation of, and modifying, the nutrient liquor. In connection with this process, however, it will be seen, that articular cartilage presents in its adult state very minute canals, which may be regarded as existing for the reception of the nutrient fluid, and

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Owen's Odontography:—"But since every secretive process, and the development of the primordial cells of every tissue are due to changes produced in the liquor sanguinis, transuded from and beyond the sphere of the ultimate capillaries, the absence of these vessels in the dense dental substance is as little conclusive against its vital and organized nature, as it would be to prove the inert condition of the germinal membrane of the ovum before the thirtieth hour of incubation."—p. 13.

for its circulation throughout the mass of the cartilage; their presence is especially required in this particular form of cartilaginous structure, from the great degree of density which it possesses.

1. *Articular Cartilage.*

Articular cartilage is situated either on the rounded extremities of long bones, or on the surfaces of flat and irregular bones. The portion of bone upon which it rests, is in some instances formed by the ossification of a distinct cartilaginous epiphysis. In non-epiphysal bones, the extremity of the shaft of the bone performs the same functions with regard to the articular cartilage situated upon it, as do the epiphyses in those bones which are provided with them. There is this difference in articular cartilage, with regard to its nutrition during and after its development; that in the former state there is no positive separation of it from the cartilage which is subsequently converted into bone, and in which its nourishing vessels are contained; whilst, in the latter state, these vessels are separated from it by an osseous lamella. The free surface of articular cartilage during, as well as after, its development, is covered by synovial membrane, to which it is attached by cellular tissue.

Around every joint, from a very early period of development, there are found numerous arteries and veins, "the articular vessels," by which their nutrition is effected.

With respect to vascularity, the nutrition of articular cartilage during its development may be divided into two stages; viz. the early one, during which no vessels enter any of the structures of the joints; and the subsequent one, in which the cartilage of the bone on the one surface, and the synovial membrane on another, are supplied with blood-vessels. In adult age, after development is completed, the same vessels continue the process of nutrition; those of the bone being situated in the cancelli, as before described, whilst those of the synovial membrane are considerably diminished in size.

In order to illustrate the nutrition of cartilage during its earliest stage, I have made the following dissections.

A. *The First Stage of Development of Articular Cartilage.*

Dissections of Articular Cartilage during the more early periods of fœtal development, before Blood-vessels enter into any of the Structures of the Joints.—a. In a fœtal Calf, which measured twelve lines from the vertex of the head to the commencement of the caudal vertebræ, the rudiments of the shaft of the os femoris were wholly cartilaginous, and measured one line in length.

The corpuscles or cells of which this cartilage was composed, were large, round, and loosely connected together.

Its extremities were smooth, and appeared to be covered by a synovial membrane, but the cells here did not present any difference from those of the shaft.

In no portion of either shaft or extremities could any vessels or canals be observed.

b. In a fœtal Calf, which measured fifteen lines between the points above indicated, the rudimentary os femoris was a line and a quarter in length, and one fourth of a line in breadth in its middle part; the extremities were somewhat expanded.

Excepting a small osseous ring at its median part, this rudimentary os femoris was entirely cartilaginous, and its cartilage was composed of large rounded cells, loosely connected together by a gelatinous substance. The cells of the articular margin differed from those in the Calf of twelve lines in length, described in the preceding dissection, in being elongated, and in having their long axis parallel with the free surface of the cartilage. The synovial surface of these cells presented a defined border, beyond which were flattened scales, each having an elongated process. There was no appearance of canals or vessels in any part of this cartilage.

c. In a fœtal Calf, measuring seventeen lines from the vertex of the head to the commencement of the caudal vertebræ, the cartilage of the inferior femoral epiphysis presented no appearance of canals. Its cells were large and round, and their connecting medium lax and easily compressible. On compressing a thick section of the extremity of the cartilaginous femur, the flattened cells of the epithelium of its synovial membrane were distinctly seen; they were as large as those of the epithelium of the mouth in the adult human subject; one of their surfaces faced the articular cartilage, the other the cavity of the joint.

d. In a fœtal Calf, measuring $2\frac{1}{2}$ inches between the points above alluded to, the os humeri, which was two lines and a half in length, was ossified to the extent of three fourths of a line at its central position. Its articular surfaces were smooth and defined, and it presented no appearance of canals. The cells towards the articular surface, as in the preceding dissections, were elongated and flat.

e. In a fœtal Calf, measuring three inches in length, the epiphysal extremities of the cartilaginous femur presented no canals, and the arrangement of the cells of the cartilage was the same as in the above dissections.

The fœtal Calves in all the above dissections had been injected, and in each case the extremities of the cartilaginous rudimentary bone were found to be surrounded by large ramifications of sanguiferous vessels.

The above observations on the nutrition of articular cartilage during the earliest periods of its development have been principally confined to preparations of fœtal Calves, from my not having been able to procure those of the human fœtus sufficiently numerous and varied for my purpose. My more limited examinations, however, of the human fœtus, have led me also to the conclusions, that during the most early periods, the cartilage of the epiphysal extremities of bones does not contain any blood-vessels, and that notwithstanding their absence, the cells of this cartilage are developed, and its growth carried on; and that at the same time the cells of the epi-

physal and the articular cartilage are formed and developed without the presence of vessels.

I think it may be naturally deduced from the facts demonstrated in the foregoing dissections,—

First. That during the most early periods of fœtal life, the growth of cartilage takes place, and that its component cells or corpuscles undergo certain progressive changes in their form and size, without the presence in its substance of any blood-vessels.

Secondly. That the vessels encircling the cartilage contribute to effect such changes in its corpuscles, and that the changes are facilitated by the softness of the substance of the cartilage.

Thirdly. That at the more early period of fœtal development the synovial surface of cartilage does not contain blood-vessels.

B. *The Second Stage of Development of Articular Cartilage.*

In the stage of development described in the preceding section, vessels are only present in the vicinity of the articular extremities of bones, but as the cartilage forming the latter becomes harder in its consistence during the subsequent periods of its development, vessels are gradually introduced upon its surface and into its substance.

Those epiphysal vessels which are subservient to the nutrition of the substance of articular cartilage, will be first treated of, and subsequently those which belong to its free or synovial surface.

The articular arteries in the adult subject, which are so numerous, and which surround so completely the various articulations, terminate by entering the substance of the extremity of the bones, by passing between the articular cartilage and the synovial membrane, and by supplying the latter membrane and the ligaments. In the stage of development which is about to be described, the ends of the bones are not yet ossified; the cartilaginous epiphysal extremities of the bones will therefore be spoken of.

First, the manner in which the branches from the articular arteries gain the interior of the epiphysal cartilage, and their mode of distribution in the subsequent periods of their development, will be demonstrated.

Secondly, the vessels which are situated between the cartilage and the synovial membrane, and which nourish the free surface of the former, will be described.

Of the Blood-vessels in the substance of the Epiphysal Cartilage.—The whole inferior extremity of the os femoris of a fœtus of about five months presents, except at its articular surface, numerous depressions of various depths. The deepest may be regarded as canals, some of which are single, others bifid; they terminate in blind sacs. The direction of some of these canals is towards the centre of the epiphysis, of others towards its point of attachment to the osseous shaft, and of others, those about to

be described, towards the articular cartilage, Plate XIII. figs. 1 and 2*. Some of these canals are of a large size, and are frequently considerably dilated at their blind extremities. They do not penetrate into the substance of the articular cartilage. These canals are for the reception of branches of sanguiferous vessels. When the epiphysis is minutely injected, the depressions upon its surface will be found to contain congeries of convoluted blood-vessels, which are more drawn out the deeper the depression, until at length, in the interior of the canals and their divisions, single, and nearly straight vessels are found. These epiphysal vessels have a very peculiar disposition. They consist of an artery having a course more or less straight, which terminates in a dilatation, or in convoluted branches, from which the vein arises, Plate XIII. figs. 3 and 4. From the fact of the presence of these vessels, which converge towards and form convolutions internal to the articular cartilage, it may be inferred that they supply the cells of the latter with a nutrient fluid. As the articular cartilage increases in thickness, and the ossific nucleus which is developed in the epiphysal cartilage becomes larger, these vessels gradually recede from between them, and they leave a considerable mass of non-vascular cartilage between the osseous nucleus and the synovial membrane; all of this appears to be articular cartilage, which is now nourished by the vessels in the interior of the nucleus. See Plate XIII. figs. 6, 7, 8, 9 and 10. The supply of blood-vessels in the cancelli of the osseous nucleus, is remarkably abundant; they are large and are separated from the surrounding cartilage by an extremely delicate lamina of bone, which is principally made up of osseous cells. I am induced to believe that at this stage of development, as in adult age, the fluid passes from the bone into the cartilage and nourishes it. From the difficulty of obtaining a series of specimens, I am unable to state the exact period at which this change in the position of one set of vessels, and the additional function in the other, takes place; but it most probably occurs at different periods in the various articulations, and it is effected in all by the time that they are called upon to encounter concussion, compression, &c. to any extent.

It may be here observed, that the articular cartilage at this early period of life is thicker than in the adult state. Although devoid of canals for the reception of blood-vessels, it presents numerous minute canals, which pervade that portion of it contiguous to the osseous nucleus, and they course from the latter towards the synovial membrane, which however they do not reach. The true nature of these canals could only be examined by powers magnifying between one and two hundred diameters. They are minute and extremely numerous; they divide, subdivide, and communicate with each other and form dilatations. The parietes of these canals present distinct rounded cells, which in some places are arranged in rows and groups. The substance between these tubes is transparent, and contains no corpuscles.

* To obtain a distinct view of these canals, the epiphysis should be macerated in water for a short time, so as to remove the perichondrium which invests it; this was done to the specimen from which the drawing was taken.

The articular cartilage, above described, is gradually being converted into bone during the whole of life; thus it is thicker in young than in adult subjects, and, as Sir Benjamin Brodie informs me, it is much thinner in old age than in the adult: in fact, it is not very rare to find that the articular cartilage of the head of the os femoris in very old persons has completely disappeared; a change which is probably to be attributed to its entire ossification*.

Of the Nutrient Vessels of Articular Cartilage during its development, which are situated betwixt it and its Synovial Membrane.—Previous to giving a description of the vessels which are present on the articular cartilage, and which are between it and the synovial membrane investing it, I must here state that I believe that the synovial membrane is extended over the surface of the articular cartilage. The valuable pathological researches of Sir B. Brodie have induced me to adopt this opinion; in addition to which, in favour of this view, the following accounts of dissections made by Henle and myself may be cited.

Henle says, "The epithelium is continued in a thinner layer on the articular surfaces of the cartilage, on which it is separated from the cartilage-corpuscles by a thin layer of cellular tissue†."

In a fœtal Calf, towards the latter part of uterine existence, I have removed the synovial membrane from nearly the entire surface of the articular cartilage of the condyle of the femur, to which it was attached by a considerable layer of cellular tissue, in which the blood-vessels that are about to be described were seen to ramify.

These vessels have been alluded to by Dr. W. Hunter under the name of "*circulus articuli vasculosus*," in the following words‡:—"All around the neck of the bone there are a great number of arteries and veins, which ramify into smaller branches, and communicate with one another by frequent anastomoses, like those of the mesentery.

"This might be called the circulus articuli vasculosus, the vascular border of the joint. The small branches divided into still smaller ones upon the adjoining surface, in their progress towards the centre of the cartilage. We are seldom able to trace them into its substance; because they terminate abruptly at the edge of the cartilage, like the vessels of the albuginea oculi when they come to the cornea."

The following is an account by Cruveilhier of the injection of these vessels§:—"Nous avons fait, MM. Breschet, Bogros et moi, des injections partielles et générales chez de très jeunes sujets; et chez des adultes, des injections partielles avec une solution d'ichthyocolle colorée avec l'indigo. Les synoviales ont été parfaitement injectés; tout autour du cartilage articulaire existe un cercle artériel duquel partent de très petites ramifications qui s'avancent sur ce cartilage dans l'espace d'une

* This appears to be another of the many instances of the disappearance of the animal, and the increased deposit of the earthy constituents of the body in old age.

† Müller's Archives, 1838, p. 116.

‡ Philosophical Transactions, 1743.

§ Observations sur les cartilages diarthrodiaux, Archives Générales de Médecine, vol. iv. p. 162, 1824.

demi ligne à une ligne, mais qui s'arrêtent toujours dans le point précis, où la synoviale cesse elle même d'être indistincte."

The arteries passing between the synovial membrane and the articular cartilage may be considered as the terminal branches of the articular vessels.

Before they reach the articular cartilage they are but laxly covered by the synovial membrane, but at the border of the cartilage they are firmly bound down to it by the very small quantity of dense cellular tissue existing between them. It is difficult to state generally at what period of fœtal existence the vessels, which have been spoken of in the first stage as forming convolutions around the joints, are prolonged upon its surface, and I can only here give the result of my investigations upon the subjects which I have been able to inject and examine.

I have studied with care the stages by which these vessels are prolonged upon the head of the os femoris at the point where the ligamentum teres is attached.

At between the *third and fourth* months of fœtal life, these vessels are simply a mass of delicate convolutions situated beneath the synovial membrane; at the *fifth* month these convolutions are somewhat unravelled, so as to extend over the surface of the cartilage to the distance of about half a line (Plate XIII. fig. 11.); and at between the *seventh and eighth* months they are drawn out and prolonged to the distance of a line and a half, Plate XIV. fig. 1. At this stage, these vessels consist of arteries of considerable size, which radiate in a straight course from the attachment of the ligamentum teres. They give off but few branches, and, previous to terminating, they divide and subdivide, but do not diminish much in size. They terminate by turning and forming loops with the small veins. Subsequent to the *eighth* month, these vessels begin to recede in their course; and at birth, and the periods subsequent to it, they are again found to be gathered immediately around the point of attachment of the ligamentum teres. After these vessels have receded, the position they occupied at the more early periods may be for some time detected by the white aspect of the cellular tissue between the cartilage and the synovial membrane. In the knee-joint of the human fœtus of five months, these vessels extend to a considerable distance over the surface of the articular cartilage, and in the fœtus at birth, although they have receded considerably, they still occupy the inferior surface of the articular cartilage (Plate XIV. fig. 2.); in adult age they have entirely receded from it.

These vessels in the knee-joint have a different mode of distribution from those above-mentioned in the hip. The arteries take a straight direction towards the centre of the articulation, and in their course they give off small branches, which, in the space between them, form a delicate network, and communicate with small veins. These arteries terminate either by turning in their course and forming broad loops with the venous radicles, or they empty themselves into a single vessel from which the veins arise, Plate XIV. fig. 2.

These vessels form a band which surrounds the circumference of the articular cartilage in all joints, as has been above stated.

In the fœtus, the vessels forming the band are long, while in the young and adult subject they are shorter, having receded to the margin of the cartilage which is not subject to concussion.

In the fœtal subject this band is more broad in some parts than others; but those portions of it which project to an inconsiderable extent over the surface of the cartilage, have, on the opposite part of the circumference, others which project to a considerable extent.

Various Characters of the Synovial Vessels.—These synovial vessels consist of arteries which take a direction towards the centre of the articular cartilage, and of veins which take a retrograde course. The arteries become continuous with the veins in the following ways:—1st, the artery becomes directly continuous with the vein without undergoing any change in its size, forming with the latter a simple loop (Plate XIII. fig. 1.); 2ndly, numerous arteries terminate in a single vessel from which veins arise; (this disposition is evident in the knee-joint, Plate XIV. fig. 2. and Plate XIII. fig. 5.); 3rdly, the artery terminates in largely dilated vessels, from which the veins take their origin, Plate XIII. figs. 3 and 4.

The preceding account of the examination of the vessels of articulations at early periods, shows that a large quantity of blood-vessels exists both at the free and attached surface of articular cartilage during its development. The modes in which these vessels are disposed, the dilated, plexiform, and other characters which they present at the point of communication of the arterial with the venous system, are interesting features in the anatomy of the vascular system, and their presence here must be associated with the large quantity of fluid required for the nutrition of the articular cartilage during development, and which is eliminated from the blood whilst its course is retarded in these vessels*.

C. *Adult Articular Cartilage.*

I have now to speak of the nutrition of articular cartilage when perfectly developed, and subject, in the performance of its functions, to violent concussion, compression, &c.

In reference to the *structure* of adult articular cartilage, it has already been stated that at its attached surface, viz. at the part where it joins the osseous lamella, it presents numerous fine canals, which can be seen only with the higher magnifying powers. These canals are irregular in their distribution; some are merely dilated cavities; frequently several of these cavities are elongated, and arranged serially, running from the attached towards the free surface of the cartilage. At the free or synovial surface, these canals do not exist; the cells of the texture at this part being elongated

* I have frequently found the sac of the synovial membrane full of colourless size, in joints of which the vessels have been successfully filled with an injection composed of size and vermilion.

and flattened, and having their long diameters parallel to the free surface. These canals contain a transparent fluid, which is seen to ooze from them after a section.

It is most probable that the uninjected vessels observed in sections of cartilage by Meckel, Bichat, and others, were these canals and sinuses.

Into the substance of healthy articular cartilages, I have never been able to trace blood-vessels, and my researches induce me to believe that they do not possess any. Previous to proceeding with my investigations upon this subject, I will give the statements of preceding inquirers with respect to the vascularity of articular cartilage.

Sir B. Brodie, in speaking of articular cartilage, states, "Here is a morbid alteration of structure, the occurrence of which seems to indicate that there must be such a vascular apparatus entering into the formation of cartilage, as enables new materials to be deposited and old materials to be absorbed*."

Bichat recognizes "a vascular system in cartilages, but he was ignorant of the nature of the white fluids which circulate in them†."

M. Beclard. "These cartilages (the articular) have no vessels‡."

M. Boyer. "Leurs (les cartilages articulaires) vaisseaux sanguins sont si petits, qu'il est impossible de les suivre dans leur épaisseur; ces vaisseaux viennent d'un réseau vasculaire qui entoure la partie de l'os comprise entre l'attache du ligament capsulaire, et le bord du cartilage, vers lequel ils s'avancent; ils s'enfoncent entre l'os et le cartilage dans l'épaisseur duquel ils envoient sans doute un grand nombre des ramifications§."

M. Cruveilhier. "The diarthrodial cartilages do not present any trace of organization‖."

M. Meckel. "Cartilages do not receive vessels which carry red blood, although in cutting them, distinct vessels are frequently observed in their substance¶."

M. Müller. "The tendons, ligaments and cartilages have blood-vessels, although in small number**."

Since the foregoing quotations were made, I have read with much interest some observations upon the subject by Mr. Liston. I subjoin the following extracts from them. "The possibility of cartilage being acted upon, nourished, absorbed, and repaired by its own vessels, must thus be admitted." Mr. L., however, adds, "This cellular tissue (between the cartilage and bone) is scarcely demonstrable in the healthy condition of parts, any more than is the vascularity of the articular cartilage††."

* Pathological and Surgical Observations on the Diseases of the Joints. Third Edition, 1834, p. 92.

† Anatomie Générale, Article, *Organization du Système Cartilagineux*.

‡ Elements of General Anatomy. Knox's Translation, 1830, p. 246.

§ Traité d'Anatomie, vol. i. p. 60. Quatrième Edition.

‖ Observations sur les cartilages diarthrodiaux, Archives Générales de Médecine, vol. iv. p. 162.

¶ Manuel d'Anatomie, vol. i. p. 354.

** Elements of Physiology, Translated by Dr. Baly, vol. i. p. 384.

†† Medical and Chirurgical Transactions, vol. xxiii. pp. 94, 95.

In adult life, when the epiphysal cartilage has been ossified, the cancelli of the latter are separated from the articular cartilage by a layer of bone, to which may be given the name of the articular lamella. The nature of this lamella is worthy of particular attention. It is composed of two sets of osseous layers; the one, dense and thick, is continuous with the vertical fibres of the cancelli; the other, delicate and thin, principally composed of osseous corpuscles, is situated at right angles to the latter, and fills up the interspaces of the vertical fibres*. See Plate XV. figs. 2 and 3.

It will be seen that the structure here delineated is admirably calculated to receive shocks, and sustain great forces. The drawing was taken from the inferior extremity of the os femoris, to which the articular extremities of all bones more or less intimately correspond.

Is this articular lamella complete? I have never been able, by the aid of the microscope, to discover any orifices in it, nor have I been able to force mercury through it.

If the articular surface of a bone, which has been minutely injected, be permitted to dry, the adipose substance, a quantity of which is generally found in the interior of the cancelli, in some measure permeates the osseous articular lamella, rendering it transparent, and their contents may then be seen and examined. To facilitate this examination, I have in some instances resorted to the application of varnish, and in others have removed the earthy particles from the bone by the aid of acid. Through the articular lamella numerous vessels of considerable size will be distinctly recognized in the interior of the cancelli. These vessels enter the substance of the bone by the large foramina which are seen at its non-articular surfaces, and they converge towards the articular lamella. With the inner surface of this lamella, they not unfrequently appear to be in contact; and either in contact with it, or near to it, these vessels form dilatations and convolutions, and then take a retrograde course and become continuous with the venous system. The vessels here described are represented as they exist towards the articular lamella in the cuneiform and cuboid bones of the adult human subject, Plate XV. figs. 4 and 5.

It is worthy of remark, that the vessels which are contiguous to the articular lamella are of a considerable size.

The existence of minute orifices in the articular lamella must be acceded to by those writers, who entertain the opinion, that vessels pass from the cancelli into the cartilage. I have been unable, as I have above stated, to detect the presence of these minute orifices, nor have I been able to see near this lamella, the minute vessels which are supposed to pass through them.

I believe that the large vessels which I have already described as forming convolutions and dilatations at the inner surface of the articular lamella, have the function

* The cribriform appearance of this lamella, seen in cases of extensive disease of the articular cartilage, is produced by the absorption of the thin and the persistence of the dense layer.

of supplying the articular cartilage with a nutrient fluid, and that they do so without entering into its substance. It is necessary that the nutrient fluid brought to the inner surface of this lamella should penetrate its substance. It is most probable that it traverses only the thin layer of the lamella, and not the vertical portions. This thin layer has already been stated to be almost entirely composed of osseous corpuscles, which without doubt assist to convey the fluid from the cancelli into the cartilage.

It appears to me, that not only those vessels which are in immediate contiguity with the articular lamella have the function of nourishing the articular cartilage, but that the large and very numerous vessels which ramify through the substance of the cancellous extremities of bones, and which enter them by large orifices at their non-articular circumference, eliminate into the cancelli a nutrient fluid, which passes through the articular lamella and nourishes the cartilage.

That the nutrition of articular cartilage is actually effected by vessels in the cancelli, may be inferred from their dilatations and convolutions in its vicinity, and from the absence of any other means, as shown by my injections.

In addition to my own preparations, I may refer, in corroboration of the view of the non-vascularity of articular cartilage, to a preparation presented to the Museum of the Royal College of Surgeons by Mr. Swan.

It consists of the bones of the posterior part of the cranium of a Sheep, which, subsequently to death, was allowed to remain suspended with its head downwards, so as to cause the blood to gravitate into it. The vessels forming convolutions in the canals of Havers are much distended with blood of a dark colour. The articular cartilage covering the condyloid processes is, however, perfectly white; not a particle of blood can be discovered in it.

The researches which I have made upon those morbid states of articular cartilage, in which blood-vessels are prolonged into its substance, and upon the manner in which the vessels are introduced into it, confirm the opinions here advanced. I shall defer entering upon them to another opportunity*.

Having proved, I think, that in the healthy state no blood-vessels pass from the interior of bone into the substance of the articular cartilage at its attached surface, I shall now proceed to show that no vessels enter it at its free or synovial surface.

Of the Vessels of the Synovial Membrane which cover the Articular Cartilage, and of the Nutrition by them of the latter.—In a former part of this paper, the vessels appertaining to the free or synovial surface of articular cartilage in the young subject have been described. A few additional observations upon them in the adult state are required here.

During fœtal and infantile life, previous to the period when the articular cartilages are subject to pressure, the synovial vessels extend over certain portions of them, from

* The investigations of Sir B. Brodie, Mr. Mayo, and more recently of Mr. Liston, leave no doubt that in some diseases to which articular cartilage is subject, blood-vessels are distributed throughout its substance.

which, in childhood and during adult age, owing to the functions of the joints, they are necessarily absent. At the period when the child begins to use the various joints, and subjects them to pressure, these vessels recede; and in adult life they are only found on that margin of articular cartilage which is exempt from the influence of external forces*. The arteries which pass between the articular cartilage and the synovial membrane, like those of the fœtus, may be considered as the termination of the articular arteries. At the point where the reflexed becomes continuous with the articular synovial membrane, it contains large vessels subjacent to it, which are numerous and plexiform. Immediately, however, that they enter the cellular web, between the articular cartilage and synovial membrane, they become enlarged and straight, and pass to a greater or less distance over the border of the articular cartilage, forming loops frequently with considerable dilatations, and becoming finally continuous with the veins. The free surface of adult articular cartilage appears to be nourished by the liquor sanguinis, which exudes from these looped and dilated vessels.

The following are the leading facts which the preceding researches *upon Articular Cartilage* tend to establish:—

1. Epiphysal and articular cartilage are developed and nourished in the early periods of fœtal existence, without the presence of blood-vessels in the substance of the former, or on the surface of the latter.

2. At subsequent periods, canals are formed in the epiphysal cartilage, vessels are prolonged into them, which converge towards the articular cartilage; and also vessels extend over a considerable portion of the free surface of articular cartilage.

3. At later periods, the epiphysal cartilage ossifies, and for a considerable time vessels are placed between the ossified nucleus and the articular cartilage.

4. As age advances, the osseous nucleus increases in size, the blood-vessels disappear from the cartilage which remains unossified, but the nucleus contains large and numerous blood-vessels.

5. Corresponding with the changes just noticed, is the recession of the blood-vessels from the whole of that surface of the articular cartilage which is subject to compression.

6. In adult life, the articular cartilage contains no blood-vessels; but in the cancelli of the bone at its attached surface, are numerous large vessels, from which the cartilage is separated by a delicate lamella of bone; the circumference of its free surface presents numerous dilated blood-vessels.

7. Articular cartilage during the whole of life gradually becomes thinner, by being converted into bone.

* I shall take another opportunity of discussing the pathological conditions in which, in the adult subject, these vessels extend over nearly the whole of the surface of the articular cartilage; artificial injections of them may be seen in most pathological museums.

2. *Fibro-Cartilage.*

Of the Structure of Fibro-Cartilage.

Anatomists of all ages have recognized the existence of a distinct animal tissue, partaking of the properties of both cartilage and ligament. Respecting the exact nature and composition of fibro-cartilages, the opinions of anatomists have differed considerably.

Meckel states that in them "the fibrous and cartilaginous tissues form layers which alternate more or less regularly*."

Bichat considered them to be composed "of a fibrous substance more than of a true cartilage."

Dr. Todd describes them as having "a very complicated cellular structure, composed of minute meshes, very irregular in size and shape†."

Müller describes them as follows:—"The interarticular cartilages, the intervertebral cartilages, and the cartilages of symphyses are constituted wholly of fibres, and contain none of the corpuscles peculiar to cartilages‡."

One of the most recent and able investigators in the branch of anatomy under consideration is Miescher, and his opinion agrees with that of Müller; he states that in the interarticular cartilages of the knee, which in infants E. H. Weber considered to be true cartilage, "he found both in infants and adults only the fibrous structure and no trace of corpuscles§."

Weber states that "the intervertebral substance exhibits no intermixture of cartilaginous substance‖."

Fibro-cartilages consist, as their name implies, of both fibrous and cartilaginous tissue; that is to say, I have always found them to be composed of minute fibres, and of the corpuscles characteristic of cartilage.

Fibro-cartilages may with accuracy be divided into two classes, both entering into the structure of joints.

The *first class* exists in those articulations which admit of only a slight degree of motion, and which are deprived of a synovial membrane. Such are the *intervertebral fibro-cartilages*, and the *fibro-cartilages of symphyses.*

Fibro-cartilages of *the second class* are generally called the *interarticular*. They differ from those of the first class in being more or less free, and in having both surfaces covered by synovial membrane; they are situated between the extremities of bones which are covered with articular cartilage.

In both classes the fibrous portion of the tissue is most abundant towards the

* Manuel d'Anatomie, Générale, Déscriptive et Pathologique, vol. i. p. 363.

† Encyclopædia of Anatomy and Physiology, vol. ii. p. 261.

‡ Translation of Müller's Elements of Physiology by Baly, vol. ii. Appendix, p. 4.

§ Miescher, p. 29. ‖ Ibid.

circumference, and in this portion only are blood-vessels found. In some instances, the centre of the fibro-cartilage is entirely composed of cartilaginous corpuscles. The cartilaginous portion is comparatively more abundant in young than in adult subjects, and in the latter it diminishes as age advances. This diminution of the cartilaginous portion is, doubtless, to be attributed to the gradual conversion of the cartilaginous corpuscles into fibres.

Of the Structure of the First Class of Fibro-Cartilages.—The Intervertebral Substances.—I am induced to enter upon the structure of the fibro-cartilages with some degree of minuteness, in order to remove the vague opinions of its composition which have been hitherto entertained.

I have examined the structure of fibro-cartilage in the intervertebral substance of the Mackerel.

It consists for the most part of large vesicular cavities containing an aqueous humour, in the interior of which are oil-globules and distinct nucleated corpuscles. The tissue in which these cavities are contained is of a fibrous character, though extremely lax.

The intervertebral substance of the Cod (*Gadus Morrhua*) has a composition similar to that of the Mackerel.

In the intervertebral substance of the Porpoise (*Phocæna*) I observed towards its centre, cells of considerable size containing distinct nuclei, as well as nuclei without cells. Fibrous tissue in concentric circles surrounded the central soft portion. Numerous distinct cells, similar to those in the centre, were interspersed between these layers of fibrous tissue. The cells of the central part vary considerably in size and form; some of them are double, each division presenting two central nuclei. These cells are round or oval; the central nucleus which each contains, presents a distinct nucleolus.

In a full-grown young Dog (*Canis Familiaris*) the intervertebral substance of the cervical region presents towards its centre a semifluid gelatinous mass, which is invested by a distinct capsule of fibrous substance, and from which it is easily separable. The gelatinous mass consists of numerous corpuscles of various sizes and in various stages of development. The larger ones present a granulated structure, and appear to contain small corpuscles. The gelatinous mass also contains a small quantity of delicate fibrous tissue, among which the corpuscles above noticed are interspersed. This fibrous tissue is composed of compressed corpuscles which resemble the scales of the epidermis and the epithelium, each presenting a distinct nucleus, and being attached to its fellows by an elongated and attenuated process. Towards the circumference of this central gelatinous mass the fibrous tissue becomes more abundant, in the interspaces of which the corpuscles are seen. The fibres of the fibrous tissue appear to be formed by an elongation and growth of the corpuscles of the cartilage*. The ex-

* Since I made this dissection the researches of M. Schwann have been published, from which he deduces the opinion that all tissues are developed from cells.

ternal fibrous capsule of the intervertebral substance is firm and dense. Its circumference is almost wholly composed of fibrous tissue arranged in circles, between which circles are rows of cartilaginous corpuscles. Nearer to the centre, the fibrous tissue is found to consist of distinct circular bands, separated from each other by large masses of corpuscles, and more centrally still the fibrous tissue is laxer, and the cells which are scattered through its meshes are larger and more abundant.

I shall now give an account of my examination of the intervertebral substance of the *human subject* at various periods of development.

a. In the human fœtus of the *third month* the intervertebral substance of the second and third lumbar vertebræ is firm and white at its circumference, soft, and of a leaden hue towards its centre. The central part is composed of numerous cells or corpuscles, some being round, others stellated. It also presents large masses of other cells aggregated together, and somewhat of a darker colour. Nearer to the circumference of the intervertebral substance the cells are arranged in distinct lines, and at its circumference they are elongated at each extremity, and so attenuated as to assume the appearance of fibres.

b. In a human fœtus of *seven months* the intervertebral substance is composed of the external fibrous and the central cartilaginous portions. The central portion is almost entirely composed of distinct round cells, which are found, on being traced towards the fibrous part, to become more elongated at their extremities, and to form, as it were, series of fibres. The fibrous portion is made up of circular layers of fibres, between which cells are interspersed.

c. In a human fœtus of *nine months* the central part of the intervertebral substance is soft, and is composed of cells, and of an intercellular substance. The external fibrous portion is distinct, and is interspersed with cells.

d. From the period of birth to adult age, the change undergone by the intervertebral substance, consists in the gradual encroachment of the fibrous portion upon the cartilaginous.

e. In adult age the central portion still continues to present corpuscles, although not in so great a number. They are always found interspersed through a gelatinous mass. The external fibrous portion also presents corpuscles between its circles of fibrous tissue.

f. In old age the corpuscles of the intervertebral substance are less numerous than in the adult. The fibrous tissue is also more dense and unyielding.

2. The fibro-cartilages, comprising those of the *symphysis pubis*, and of the *sacro-iliac articulation* also, consist of an external fibrous portion, and of a central cartilaginous one, which undergo the same relative changes, as age advances, as the fibro-cartilages just described.

Of the Structure of the Second Class of Fibro-Cartilages.—I have made careful examinations of all the *inter-articular* fibro-cartilages at several periods of their development and growth, and the following is the result of my inquiries concerning their

structure. They, like the fibro-cartilages of symphyses, consist of an external fibrous and of a central cartilaginous portion. At the early periods of their development, the cartilaginous is more abundant than the fibrous portion, and it is almost entirely composed of corpuscles. As age advances, the fibrous portion increases in quantity; and towards the later periods of life, the corpuscles of the cartilaginous division are mixed with fibrous tissue.

Of the Vessels of Fibro-Cartilage.

Respecting the vascularity of the fibro-cartilages, BICHAT says, "Peu de sang pénètre leur système vasculaire dans l'état ordinaire, mais dans l'inflammation ils sont extrèmement injectés*."

Professor TODD says, "They (the fibro-cartilages) are more vascular than pure cartilage, but in the natural state they admit very few vessels carrying red blood†."

MÜLLER, as quoted above, says "they have blood-vessels, although in a small number."

Of the Vessels of Fibro-Cartilages of the First Class.—1. *Of the inter-vertebral substances.*—I have made numerous injections of the intervertebral substance in Man and animals of various ages, and have found that the external more fibrous portion is pierced by arteries of considerable size; these are guarded from compression by the dense nature of the fibrous tissue through which they pass. They course towards the central cartilaginous portion, into which, however, they do not penetrate, but in its confines they form large convoluted dilatations, from which the recurrent vein arises. The extreme edge of these vascular convolutions presents a line which may be considered as the boundary between the fibrous and cartilaginous portions of the intervertebral fibro-cartilage. See Plate XV. fig. 6.

2. The following is the result of a careful examination of the vessels of the *sacro-iliac fibro-cartilage* in the human subject, at various periods of its development.

a. In the *fifth month* of fœtal existence the vessels of the sacro-iliac fibro-cartilage form a conglomerated mass of large and tortuous arteries and veins contained in the external part of the fibrous portion. Here and there a few more delicate branches diverge from this mass to a slight distance towards the central cartilaginous portion, at the border of which they terminate in dilated extremities.

b. In the fœtus of *six months* the convoluted arteries are prolonged to the circumference of the cartilage, where they divide and subdivide, each branch terminating in a dilatation, which frequently communicates with the one adjacent to it, and from this dilatation or series of dilatations the recurrent veins arise.

c. In the fœtus of *nine months* these vessels are considerably increased in length; they are more distant from each other, and their extremities no longer present the large dilatations.

* Anatomie Générale. Article, *Organization du Système Fibro-Cartilagineux.*

† Cyclopædia of Anatomy and Physiology. Article, *Fibro-Cartilage.*

More limited observations upon the state of these vessels in subsequent periods of life, lead to the belief, that, compared to the size of the fibro-cartilage, they gradually become more scanty and small from the period of youth to that of old age.

3. Researches upon the vessels of *the fibro-cartilage of the symphysis pubis* lead me to conclusions similar to those I have just related.

Of the Vessels of the Inter-articular Fibro-Cartilage.—The central part of the inter-articular fibro-cartilages, in the injected specimens that I have examined from the human fœtus as early as the third or fourth month, does not contain any vessels. I possess, however, the inter-articular cartilage of the temporo-maxillary articulation of a fœtal Calf, which is pervaded by blood-vessels throughout its entire substance; a disposition which may take place in all fibro-cartilages at very early periods of their development. Subsequent to these very early periods, however, the central portion, which, like articular cartilage, is subject to concussion and compression, does not contain any blood-vessels.

The inter-articular fibro-cartilages are pierced at their circumference by arteries of considerable size, which converge towards the central cartilaginous portion, into which, however, they do not penetrate, but upon its confines they form dilatations, with which the veins are continuous*, Plate XV. fig. 7.

In some instances, as in the sterno-clavicular fibro-cartilage, the arteries form intricate ramifications and convolutions at the circumference of the cartilage; in other instances, as in the semilunar fibro-cartilages of the knee-joints, they terminate in more simple dilatations, Plate XV. fig. 7.

The vessels of the fibro-cartilages in some parts, as in those of the knee, form a most intricate flexus in the fibrous tissue.

Vessels extend to a short distance on the surface of fibro-cartilages, beneath the synovial membrane, but they are arrested at the part where these structures are subject to pressure, and at this margin they form dilatations similar to the synovial vessels which cover the border of articular cartilages.

The Second Class of Non-vascular Animal Tissues.

Of the Cornea, the Crystalline Lens, and the Vitreous Humour.

The organs enumerated above may be considered as constituting a class of non-vascular organized tissues, inasmuch as each of them is transparent, each forms a part of the eye-ball, and performs a similar function, viz. of transmitting the rays of light to the retina. These three structures are nourished by the penetration into them of a nutrient fluid, which is derived from the numerous blood-vessels which encircle them; although each of them contains corpuscles, they differ from each other in their structure as well as in their relations with the vascular system. Thus the crystalline lens is soft externally, and hard towards its centre, and the

* For the injection of the blood-vessels of fibro-cartilage, young subjects should be selected.

vitreous humour is semifluid. In the cornea one set of blood-vessels is prolonged upon a part of its free surface; while another is in apposition with the margin which is attached to the sclerotic, and is devoted to the nutrition of the principal part of its substance. In having two sets of blood-vessels, the one devoted to the nutrition of the surface of the tissue, and the other to that of its substance, the cornea has an analogy with cartilage and fibro-cartilage. The crystalline lens receives a supply of nutrient fluid only at its surface, and by means of the ramifications of the arteria centralis retinæ, which are distributed in the capsule which surrounds it. The vitreous humour appears to be nourished by the fluid which it derives from the vessels of the ciliary processes, the latter being received into sulci of the humour. It will be observed, that the vitreous humour has vessels in contact with it only at its surface, and at a small portion only of the latter; it may be inferred that the fluid brought to this part is capable of nourishing the whole vitreous body, on account of the facility which its semifluid character allows of the diffusion of a fluid through its entire mass.

1. *Of the Cornea.*

Structure of the Cornea.—It has been stated, in the Introduction to this paper, that all the non-vascular animal tissues contain the characteristic corpuscles. The cornea does not present any exception to this assertion, although the following account by M. Müller does not appear confirmatory of the accuracy of my opinion: the following are his words:—

"The middle layer, which constitutes the chief substance of the cornea, is formed of an interlacement of bundles of bright fibres, without any intermixture of corpuscles*."

I have frequently made most careful examinations of the substance of the cornea, and I have always found corpuscles present. They are certainly not so abundant here as in some of the above-named tissues. They are better seen in sections made at right angles to the surface of the cornea, than in those parallel with its surface, and they appear to be more evident after the cornea has been immersed in spirits of wine. Some of these cells are rounded, others are oval, and have fine branches radiating from them, similar to the osseous and pigment corpuscles. These cells are surrounded by the bright fibres of which Müller has spoken; these fibres, which compose the larger portion of the cornea, are laxly connected together, so as to have some analogy with cellular tissue; the substance of the cornea being of a loose texture, and easily pervaded by fluids. I believe that the lax texture of the cornea allows of an easy penetration of its substance by the nutrient fluid which circulates around it, and thus there is not an equal necessity for the presence of the corpuscles in this, as in the more dense tissues.

* Elements of Physiology, by Baly. Appendix, p. 3.

Of the Vessels which nourish the Cornea.

Previous to giving the results of my researches upon the manner in which the cornea is supplied with a nutrient fluid, I shall detail the following opinions of authors upon its vascularity.

M. Boyer. "La cornée reçoit des vaisseaux sanguins, puisqu'elle devient rouge dans les fortes inflammations; mais ces vaisseaux sont si fins, que l'injection ne peut y pénétrer, et que la partie rouge du sang ne s'y introduit qu'en quelques circonstances. On n'a point encore découvert de nerfs dans cette membrane*."

M. Cruveilhier. "Les injections les plus fines, passées dans les veines et dans les artères de l'œil, ne démontrent aucun vaisseau dans la cornée†."

Mr. Jacob. "The cornea is destitute of red vessels, yet it affords a signal example of a colourless and transparent texture possessing vital powers inferior to no other‡."

Mr. Lawrence. "The cornea in its natural structure consists of cartilaginous laminæ and mucous membrane; the cornea is analogous to the articular ends of the bones, in which the articular cartilage is covered by synovial membrane. It (the cornea) agrees with them, (the fibrous structures) in the entire absence of vessels circulating coloured fluids; perfect transparency being essential to its office of transmitting light§."

M. Müller. "The existence of vessels in the substance of the cornea is doubtful; they have never been injected. Nevertheless, penetrating ulcers and granulations are formed in the cornea, which can scarcely be conceived to occur without the agency of vessels. I have repeatedly seen in Calves of nearly the full time, vessels in the conjunctiva of the cornea, which contained red blood, and which could with a lens be traced more than a line over the margin of the cornea. Henle has injected these vessels; in the conjunctiva of the cornea they measured $\frac{1}{1319}$th to $\frac{1}{694}$th of an inch, and the finest twigs were not then injected; their trunks, which arose from a circular vessel that ran around the cornea, were even somewhat larger than this. The preparations of these parts I have in my possession. Professor Retzius has, by means of injection, been able to see the same thing in the adult animal.

"All these facts, however, render it very probable, that even the cornea and capsule of the lens, to which vasa serosa have been hitherto ascribed, are really provided with vessels carrying red blood. The vessels of the corneal conjunctiva are certainly less numerous than those of the sclerotic conjunctiva; there is the same difference between these two parts as between that part of the synovial membrane which is free, and that which covers the articular cartilage‖."

M. Romer. "Romer of Vienna has described the arteries which ramify from the

* Traité d'Anatomie, quatrième édition, 1815, vol. iv. p. 98.

† Anatomie Déscriptive, 1815, vol. iii. p. 462.

‡ Cyclopædia of Anatomy, vol. ii. p. 177.

§ On the Diseases of the Eye, 1833, pp. 16, 368.

‖ Müller's Elements of Physiology by Baly, vol. i. pp. 215, 216.

sclerotic conjunctiva upon the cornea, from injections. The fine twigs of the arteries of the sclerotic conjunctiva unite together around the margin of the cornea into a vascular wreath or circle. From these there arise very numerous branches, which run from the circumference towards the centre of the cornea, and in their course make two or three subdivisions. Their ends bend distinctly inwards, and appear to penetrate the proper substance of the cornea*."

Mr. Tyrrell. "I have been thus satisfied that the vascular organization of the cornea is principally derived from the conjunctiva, and little, if at all, from the sclerotic vessels†."

Mr. Wardrop. "It (the cornea) is also nourished by the same vessels which supply the conjunctiva‡."

There is very considerable difficulty in making a complete injection of the vessels, which have the function of supplying the cornea with a nutritive fluid§.

The vascular system of the cornea resembles that of articular cartilage, in consisting of two sets of vessels, one of which is devoted to the supply of its substance, and which is in contact with its margin where it is attached to the sclerotic; the other supplies its free or mucous surface, the circumference of which it overlaps.

In an eye which is injected with tolerable success, the white sclerotic membrane will be observed to be traversed by two sets of vessels. One of these consists of small and numerous branches, which have a straight direction towards the circumference of the cornea. These are the ultimate branches of the sclerotic arteries which course towards the cornea. The other set of vessels is composed of the large and tortuous trunks which are seen with ease by the naked eye; these are the sclerotic veins, which take a retrograde course to the arteries just alluded to, and become gradually larger as they get more remote from the cornea; these sclerotic veins return the blood devoted to the nutrition of the cornea.

Upon examining *the arteries* with a magnifying glass, they will be found, at the circumference of the cornea, to terminate in two sets of vessels; of these, one is superficial, and consists of delicate branches which pass inwards over the surface of the cornea, between it and its mucous covering, and are analogous to the vessels of joints which pass between the articular cartilage and the synovial membrane. The other set of vessels, in which the sclerotic arteries terminate, are much larger than those just noticed, and are more like the continuation of their trunks; these, at the circumference of the cornea, pass into the substance of the sclerotic, where they come in contact with the attached margin of the cornea.

* Mr. Wharton Jones, Medical Gazette, vol. xxiii. p. 593.

† Medical and Chirurgical Transactions, vol. xxi. p. 17.

‡ The Morbid Anatomy of the Human Eye.

§ I have made more than fifty injections of the eye, and I possess only three specimens in which the vessels alluded to are successfully filled.

The *superficial or conjunctival* arteries, upon arising from the sclerotic, take a course parallel with the circumference of the cornea, and are sometimes so long as to receive the name of its circular vessels; from these, branches are given off which pass in a direction towards the centre of the cornea. These, after division and subdivision, form a minute plexus on the border of the latter, and they terminate on its surface from one-eighth to half of a line from its circumference, by becoming continuous with the venous system, Plate XVI. fig. 1.

The modes in which the arteries are continued into *veins*, are various; sometimes they form loops with the venous radicles; sometimes a single arterial branch divides, and both of its divisions take a course retrograde to that of the artery, and they empty themselves into the venous plexuses. This species of vascular arrangement is seen in Plate XVI. fig. 1. Sometimes the artery divides into two or three branches which form loops with a venous radicle. These vessels appear to differ much in their sizes; this difference perhaps depends upon whether, as in the specimen from which the fig. 1. was taken, they only contain a sufficient quantity of colouring matter to enable their course to be traced with distinctness. The small *veins*, which are continuous with the arteries just described, take an opposite course to the latter, and upon reaching the margin of the sclerotic, they empty themselves into the large tortuous veins, which have been noticed above, just as the latter are emerging from the substance of the sclerotic, where it is attached to the cornea.

The *deep or sclerotic arteries* of the cornea are those from which this structure derives its chief nutrition. They are large enough to be considered the continuation of the trunks of the sclerotic arteries; they pass without much diminution of their size towards the point where the sclerotic membrane is continuous with the cornea. At the margin of the latter they suddenly stop and turn back, forming loops; sometimes with, and at other times without dilatations, they become continuous with the veins, Plate XVI. fig. 2. These veins emerge from the substance of the sclerotic, close to the margin of the cornea, at which point they receive the conjunctival veins; and they take a backward course, and form those tortuous veins which have already been noticed, and which are seen by the naked eye.

Such are the investigations which have induced me to state, in the introduction to this second class of tissues, that the cornea in a healthy state does not contain any blood-vessels. The vessels which have the function of supplying this tissue with a nutritive fluid, are those belonging to the two classes which I have described.

In a diseased state, the vessels which, in the healthy condition terminate abruptly at the margin of the cornea, are prolonged through its entire substance; while those which, when healthy, extend over the surface of the cornea from the one-eighth to half of a line, in disease form a band of considerable extent. I shall defer entering upon these pathological conditions to a future opportunity.

2. *The Crystalline Lens.*

Of the Structure of the Crystalline Lens.—According to the researches of M. Schwann, the crystalline lens, in the earliest periods of its development, is entirely composed of cells; and it is the opinion of Valentin and himself, that these cells are converted into the fibres of the lens. The dentations of the fibres of the lens are compared by M. Schwann to the sinuosities of a not uncommon form of vegetable cells*.

In the examinations that I have made of the crystalline lens, I have not only found cells interspersed among its fibres, but have frequently seen the fibres themselves, composing the external part of the lens, made up of these cells; and in other instances they occupy the margin of the fibres only.

Of the Blood-vessels which nourish the Crystalline Lens.—The crystalline lens, in a healthy state, has never been seen to contain blood-vessels. Müller, in speaking of the mode of development of this organ, says, "The matrix of the crystalline lens is its capsule, which seems to secrete the layers of the crystalline from its inner surface." The presence of vessels in its substance would certainly interfere with the functions of the crystalline lens; for, as I have said, perfect transparency is essential to its office of transmitting light. In the anterior capsule, according to Müller, "the vessels are extremely difficult to inject;" he however states that "in inflamed eyes they are distinct, both on the anterior and posterior walls of the capsule." The presence of blood-vessels in the anterior capsule of the lens would as effectually derange the functions of the eye, as if they were in the substance of the cornea, or in the lens itself.

I have not only been unable to trace vessels into the anterior capsule, but I hope to prove that in the healthy state no vessels do enter it. The posterior capsule of the lens is, however, injected with facility, and contains large and numerous ramifications of blood-vessels; I ascribe to them the function of supplying the crystalline lens with a nutrient fluid. These vessels arise from the arteria centralis retinæ; the latter, having traversed the centre of the vitreous humour, expands upon the capsule, and forms the ramifications just noticed. Now in some injections which I have made of the eyes of a human fœtus, of the sixth or seventh month, these vessels were not confined to the posterior surface of the capsule; they pass round its border and extend upon its anterior face to the extent of one quarter of a line. I have not been able to make a perfect injection of the vessels of the capsule of the lens in ages antecedent to the fifth or sixth month of the fœtal life, and therefore am unable to say whether in the very early periods of development, the anterior capsule, like the membrana pupillaris, is entirely traversed by vessels; the crystalline lens would, under such circumstances, be completely surrounded by blood-vessels.

The branches of the arteria centralis retinæ in the early periods of life, as noticed

* British and Foreign Medical Review, vol. ix. p. 512.

above, extend upon the anterior surface of the capsule. Immediately they reach the latter they become straight, run parallel with each other, and are directed towards the centre of the anterior surface for the distance of a quarter of a line, when they stop in their course, and form looped dilatations, which give origin to small veins, Plate XVI. fig. 6. It is most probable that these vessels recede at subsequent periods of development, so as to leave the whole of the anterior surface of the capsule capable of being permeated by the rays of light*. These vessels, in a diseased state, are sometimes prolonged into the whole of the anterior capsule, (or to speak with more propriety, the anterior half of the capsule,) where, in morbid specimens, they have been injected by Schroeder Van der Kolk. The capsule of the lens is thus pervaded by large and numerous ramifications of blood-vessels, which I believe pour out upon its inner or lenticular surface a nutrient fluid; this *fluid will immediately come in contact with* the mass of delicate cells described by Schwann as situated between the lens and the capsule.

The mode of nutrition of the crystalline lens may be explained, by supposing that the nutrient fluid is received by the cells just alluded to, and conducted to the lens (perhaps has its characters changed in its course by the metabolic functions ascribed to them by M. Schwann) through which it is diffused. It has been stated, that the presence of blood-vessels in the cornea, the anterior half of the capsule of the crystalline lens, and in the substance of the lens itself, appears to be incompatible with their function of transmitting the rays of light to the retina. Nevertheless large vessels ramify on the posterior half of the capsule. The knowledge of the existence of this arrangement of vessels led me to perform some experiments with lenses, from which I have deduced the fact, that objects (radiating lines, for instance) situated on the *anterior* surface of the crystalline lens, produce an indistinctness in the image which is formed upon the retina; whereas, when these lines exist upon the *posterior* surface of the lens, the image is perfectly clear.

3. *The Vitreous Body or Humour.*

Structure.—The vitreous humour is composed of cellular cavities which are filled with a transparent fluid. The membrane of which the walls of these cells are composed,—the tunic of the vitreous humour,—is very delicate, and is interspersed with corpuscles.

The Vessels of the Vitreous Humour.

Many anatomists† have stated that the arteria centralis retinæ, in its course through the vitreous humour, gives off minute branches into the substance of the latter; but these branches have never been described; on the contrary, Müller, who has paid

* I have hitherto not succeeded in making a complete injection of these vessels in the adult subject.

† Harrison, Boyer, Cruveilhier, &c.

especial attention to this subject, and has examined injections of inflamed eyes, says, "I have not seen any injected vessels in the vitreous body;" and adds, "I do not despair of seeing this part also injected*."

Since the above was written, I have met with the following account of an injection of the membrane surrounding the vitreous body:—"Mr. Dalrymple has succeeded in injecting a number of minute ramifications, of very delicate vessels, on the periphery of the membrane (of the vitreous body) derived from a branch or branches of the central artery, which passed by the spot termed the foramen of Söemmering; he kindly permitted me to inspect the preparation, which was most satisfactory, but which I much regret has been since destroyed by accident†."

My researches induce me to believe that the vessels of the vascular ciliary processes of the choroid membrane, to which no specific function has hitherto been given, have the function of nourishing the vitreous body. My opinion is confirmed by that of Müller, who says, "The zonula Zinni, or corona ciliaris, appears from Henle's and Schroeder's injections, to be a vascular organ, and to be of great importance for the nourishment of the transparent humours‡."

I have succeeded in making very minute injections of the vessels of the ciliary processes, the disposition of which is remarkably beautiful; they have been most accurately delineated and described by Zinn. I have particularly to allude to the immense quantity of blood that their large size allows to be continually circulating through them, and to their plexiform character, which is productive of a slow circulation of the fluid they carry. At the free border of each ciliary process is a large single vessel, which is received into the base of the sulcus of the vitreous humour, and is in immediate contact with it. When it is remembered that the investing membrane of the vitreous humour is very delicate, and that it is made up of cells or corpuscles, and that it has in immediate contact with its free surface these large and numerous vessels, they may perhaps with great reason be considered as the organs of nutrition of the vitreous humour, by eliminating a nutrient fluid which penetrates into, and is diffused through, the substance of the latter.

The Third Class of Non-vascular Animal Tissues.

Of the Epithelium, the Epidermis, Nails and Claws, Hoofs of various kinds, Hair and Bristles, Feathers, Horn and Teeth.

The above structures are placed together as forming a distinct class of extravascular tissues, on account of their being all developed upon the surface of the chorion, and very analogous to each other in their structure, their mode of growth and

* Müller's Elements of Physiology by Baly, vol. i. p. 216.

† A practical work on the Diseases of the Eye, by F. Tyrrell, p. 97.

‡ *Loc. cit.*, p. 219.

nutrition. Each of them is in contact, at its attached surface, with numerous and large branches of the vascular system, and, with the exception of the teeth, each is almost entirely composed of corpuscles or cells, which are of a somewhat circular form, where they are near to the vascular chorion, and are compressed and flattened where they are further removed from it. These tissues grow, by the addition to them, at their point of attachment with the chorion, of new cells, and from the increase in size of those already developed*.

The Epithelium is composed of corpuscles which are round where they are in contact with the vascular chorion, and of others which are flat and in the state of scales situated at its free surface. Immediately subjacent to the epithelium the chorion presents ramifications of blood-vessels which nourish it, and which have different characters in different portions of the mucous membrane, according to the various functions which they have to perform.

The chorion of the *Integuments* of the human subject, where it is subjacent to the thin and delicate cuticle, presents a minute and intricate network of blood-vessels. The arteries divide, subdivide, and form a network, from which the veins arise. The vessels of the chorion, however, are differently arranged, where it is covered by thick and dense cuticle. Thus, it is well known, that at the palms of the hands, the anterior surface of the extremities of the fingers, the posterior part of the heel and at the sole of the foot, the thick *Epidermis* forming corns, &c., the arteries of the chorion are observed to terminate in numerous dilated loops, a disposition which bears a close analogy to certain synovial vessels.

The vessels of the chorion have the function, not only of secreting the perspiration, but of developing and nourishing the ducts through which the latter fluid is excreted†.

In parts where the *Epidermis* undergoes a still greater degree of condensation, and is found in larger masses than in parts already alluded to, the vascular system of the chorion presents still greater dilatations, and more complicated arrangements. Such parts are the nails and claws, hoofs, hair and bristles, feathers and horn.

The Nails.—Where the nails are in cohesion with the vascular chorion, they are more or less soft; and when portions of them at this part are examined by the microscope, they are seen to consist of corpuscles somewhat compressed and connected to-

* In the first edition of his Elements of Physiology, page 384, Müller enters upon an examination of the mode of growth "of unorganized non-vascular parts." These he divides into three classes:—1. The horny tissues; 2. The teeth; 3. The crystalline lens. In the second edition, p. 416, having omitted the word unorganized, he adds, "These parts, however, though not vascular, and though formed in the manner which we have described, have nevertheless a definite structure or organization, and afford confirmation of our previous remarks, that the vessels are merely destined to pour out the materials for nutrition, and that the formation of the elementary parts of each tissue takes place in the matter effused independently of any action of the vessels."

† The walls of the perspiratory ducts of the cuticle appear to me to be formed of a single filament (itself composed of corpuscles) spirally arranged, having thus an analogy with the spiral ducts of plants.

gether by a gelatinous substance. The harder part of the nail consists of compressed and transparent corpuscles.

Although the nails do not contain any blood-vessels, they change their colour and become friable under certain conditions of the circulation, thus showing that their component cells have the power of circulating through them the fluid which is brought to them by the blood-vessels, at their attached surface.

The nails are in contact with the vascular chorion at two points; their attached margin is inserted into a groove of the chorion, and the attached surface lies upon that portion which covers the dorsum of the terminal phalanges.

The vessels which have the office of supplying the nail with a nutrient fluid are large and numerous. The arteries take their origin from the digital trunks, and they converge towards the dorsal surface of the terminal phalanx, on which they ramify, and where they may be considered to terminate in two sets of vessels; one of which is devoted to the supply of the ungual groove, the other to the ungual surface of the phalanx. The ungual groove is very vascular; it presents the ramifications of arteries, which, after division and subdivision, form large plexuses in the margin of that part of the groove which overlaps the nails, and the arteries terminate in loops of considerable size. The vessels of the ungual surface are of a considerable size; they form large convolutions; these give off branches, which, with others from the interior and lateral part of the phalanx, form an intricate capillary network, which is in immediate opposition with the attached surface of the nail.

The Claws and Horns of quadrupeds, and the claws and beaks of birds, have a structure very analogous to the nails of the human subject. They are in contact, at their attached surface, with large vessels. In some instances the bone upon which they rest is perforated by foramina, the chorion subjacent to them, and between them and the bone, is very attenuated, and they appear to be nourished also by the vessels contained in the bone itself.

Hoofs can be considered only as condensations of the cuticle. In fœtal Calves, at an early period of their existence, the hoof is not thicker than the cuticle of the heel of the adult human subject, to which it is analogous in its structure. In adult age that part of the hoof which is in connection with the chorion retains its analogy with the cuticle, but at its free surface it becomes hard and somewhat friable. It is impossible for me here to enter into the details of the structural varieties of the hoofs of animals, so as to point out any peculiarities in their composition which shall assist in diffusing the nutrient fluid through the whole of their substance, to endow it with the elasticity essential to the due performance of its functions. I will content myself with stating, that it appears to me that the use of the elongated tubes containing white soft matter, and which pervade the substance of the hoof of the Horse, is to convey through its substance the fluid secreted at its attached surface.

The chorion subjacent to the hoofs of animals presents two different characters, the one being that of numerous fine villosities, the other of compressed lamellæ; these are revived into depressions on the surface of the hoof, and are composed of vessels which terminate in loops, possessing frequently considerable dilatations.

Hair and bristles, of various kinds, in the neighbourhood of the vascular chorion, are composed of roundish corpuscles loosely connected; more remote from the chorion, their substance is harder; the corpuscles are flattened, and they appear to possess the characters of horn. The chorion, with which the hair is connected, consists of a papilla, which is inserted into the interior of the base of the hair, and of a sheath or capsule which surrounds it; both the papilla and capsule are supplied with large and numerous blood-vessels, which form loops and dilatations.

Feathers.—In his elaborate article "Aves," in the Cyclopædia of Anatomy and Physiology, Professor Owen, after quoting the interesting observations of himself, Sir W. Jardine, Mr. Blyth and Mr. Yarrell, on the changes that take place in the colour of the plumage of birds subsequent to their complete development, says, "Notwithstanding the extra-vascular nature of feathers, they are subject to influences apparently of a vital nature, which occasion a change of colour in them after they are completely formed."

Feathers near to the vascular chorion consist of corpuscles more or less compressed; further removed from the chorion they are highly compressed, and present a similarity to the hair. The chorion to which the feathers are attached presents a pulp and capsule, which have a disposition of vessels analogous to those of the hair.

The Teeth are now considered to be permeated by an infinity of fine tubes, which are supposed to have the function of conducting from the surface of the vascular pulp, a nutrient fluid, which is distributed over the substance of the tooth. In this way may be explained the manner in which the teeth change their colour during diseases, being impregnated by the various fluids circulating in the system*.

From the preceding observations by myself, and from those made by the physiologists whose writings I have quoted, I think it is established, as a general law in Animal Physiology, that certain tissues are capable of being nourished without the presence of blood-vessels within them: it has been shown that all these tissues are surrounded by large blood-vessels, which appear to have no other function than of supplying to them a nutrient fluid; and the way in which this nutrient fluid is conveyed into the substance of these tissues has been also pointed out.

* Recent investigators have thrown so much light upon the structure and the mode of growth of the *Epidermoid Class* of non-vascular tissues, that (as is apparent) I have added but few new facts in this department of my researches.

The analogy between the extra-vascular animal and the vegetable tissues is manifest.

The application of the above-named law to the study of *Surgery*, in reference to the causes of the prolongation of vessels into the extra-vascular tissues, and to the measures to be adopted for the prevention and cure of those diseases which are dependent thereon; and to *Pathology*, in the investigation of the nature of morbid structures, particularly of those classes which contain no vessels,—will, I feel certain, be productive of interest and great advantage.

In conclusion, I have to thank my estimable friend Mr. Edward Dickinson, for the many acts of disinterested kindness he has conferred upon me, which have tended much to supply matter to this paper.

Every one will see how much I owe to the skill of Mrs. Holmes.

My brother, Mr. George Toynbee, by the valuable assistance he has afforded me in editing and arranging this paper, has added another to the many deep obligations which I owe him. For his good counsel, from the time I entered the profession to the present day, I am more indebted than words can express.

Explanation of the Plates.

PLATE XIII.

Fig. 1. The anterior surface of the inferior extremity of the femur of a human fœtus of about four or five months. It has been macerated for some time in water, and the cartilage of the epiphysis is somewhat transparent, so that a canal for the epiphysal blood-vessels is seen in its substance.

A. The orifice of a canal.

B. The synovial surface of the cartilage.

Fig. 2. A section of a similar extremity of the femur of a human fœtus somewhat older.

A. The osseous cylinder of the femur.

B. The cartilaginous epiphysis.

C. Canals for the blood-vessels.

D. The synovial surface of the cartilage.

Fig. 3. The blood-vessels which are contained in the canals of the epiphysis.

A. The artery.

B. The dilatations with which the arteries and veins are continuous.

C. The veins.

Fig. 4. The blood-vessels contained in a longer epiphysal canal.

A. The artery.

B. The intermediate dilatation.

C. The vein.

Fig. 5. A plexus of blood-vessels situated between the synovial membrane and the circumference of the articular cartilage; from the same specimen as fig. 3.

Figs. 6, 7, 8, 9 and 10. Diagrams of the inferior extremity of the os femoris, to show the relations of the blood-vessels with the articular cartilage, and the osseous nucleus of the epiphysis, during the different periods of their development.

Fig. 11. Vessels situated between the attached synovial membrane and the articular cartilage, at the point where the ligamentum teres is inserted in the head of the os femoris of the human subject, between the third and fourth months of fœtal life. (Magnified thirty diameters.)

A. The surface of the articular cartilage.

B. The vessels between the articular cartilage and the synovial membrane.

C. The surface to which the ligamentum teres was attached.

D. The vein.

E. The artery.

PLATE XIV.

Fig. 1. Vessels similarly situated to those of fig. 11. Plate XIII. but between the seventh and eighth months of fœtal life. (Magnified thirty diameters.)

A. The surface of the articular cartilage.

B. The vessels between the articular cartilage and the synovial membrane.

C. The surface to which the ligamentum teres was attached.

Fig. 2. Vessels situated between the synovial membrane and the articular cartilage on the circumference of the condyle of the os femoris of the human fœtus, at the period of birth. In one part the arteries are observed to terminate in a single vessel from which the veins take their origin; in another part the arteries communicate with the veins by means of loops. (Magnified thirty diameters.)

A. The surface of the articular cartilage.

B. The vessels between the attached synovial membrane and the articular cartilage.

C. The reflexed synovial membrane.

D. The lateral surface of the condyle of the femur.

PLATE XV.

Fig. 1. Vessels situated between the attached synovial membrane and the articular cartilage at the circumference of the head of the metatarsal bone of the human subject.

Fig. 2. A vertical section of a portion of the inferior extremity of the os femoris. Natural size.

A. The horizontal lamella, to which in the recent state the articular cartilage is firmly attached, and which separates the latter from the cancelli of the bone.

B. The vertical fibres of the cancelli; these are implanted into the upper surface of the articular lamella.

Fig. 3. A portion of the inferior extremity of the os femoris slightly magnified.

A. The articular lamella.

B. The cancelli of the bone.

Fig. 4. Displays the manner in which the blood-vessels are disposed in the cells of the cuboid bone, internal to the articular lamella. This lamella has been rendered transparent, and the vessels are seen internal to it.

Fig. 5. A vertical section of a cuneiform bone of the human foot, and of the articular cartilage which is implanted upon it.

A. The interior of the bone.

B. The articular lamella.

C. The articular cartilage.

Fig. 6. The blood-vessels of the intervertebral substance; the arteries traverse the fibrous portion, and terminate at the circumference of the central cartilage in large dilatations.

Fig. 7. The semilunar fibro-cartilage of the knee-joint from a young human subject.

A. The central part not containing blood-vessels.

B. The external fibrous and vascular portion.

PLATE XVI.

Fig. 1. Represents the mode of distribution of the blood-vessels on the free surface of the circumference of the cornea. (Magnified thirty diameters.)

A. A portion of the cornea.

B. The blood-vessels situated on the surface of the cornea, being covered by the membrana conjunctiva.

C. A portion of the membrana sclerotica.

Fig. 2. Represents the blood-vessels which are situated in the substance of the membrana sclerotica where the cornea is attached to it. (Magnified thirty diameters.)

A. The cornea.

B. The sclerotic vessels.

Fig. 3. A highly magnified view of the blood-vessels in the membrana sclerotica at the circumference of the cornea.

A. The cornea.

B. The membrana sclerotica.

Fig. 4. A plexus of blood-vessels situated on the surface of the circumference of the cornea, between the latter and the membrana conjunctiva.

Fig. 5. A plexus of vessels similarly situated to that of fig. 4.

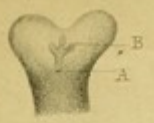
Fig. 6. Displays the manner in which the blood-vessels that ramify on the posterior part of the capsule of the crystalline lens are disposed at the circumference of the anterior surface of the capsule. From a human fœtus of between four and five months.

A. The anterior surface of the capsule of the crystalline lens.

B. Blood-vessels situated on the anterior surface of the capsule at its circumference.

[In the above Plates, the arteries, dilatations and veins, are distinguished from each other by the difference in the mode of engraving.]

Fig. 1.



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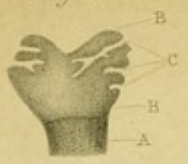


Fig. 3.

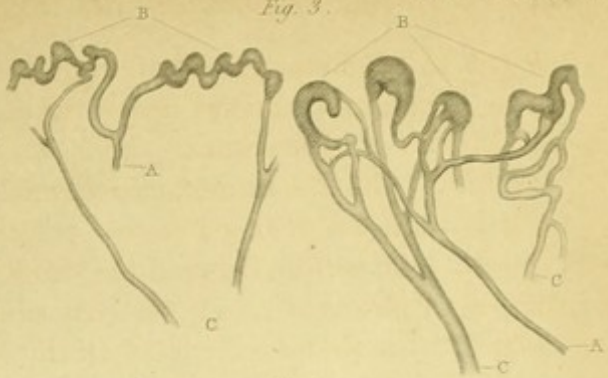
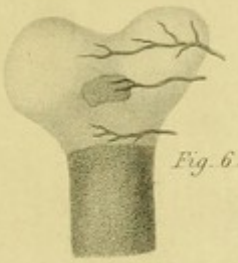


Fig. 4.

Fig. 5.

Fig. 6.



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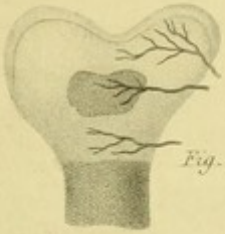

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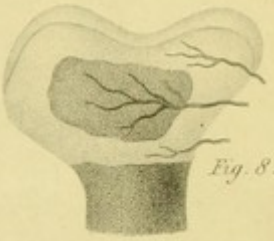

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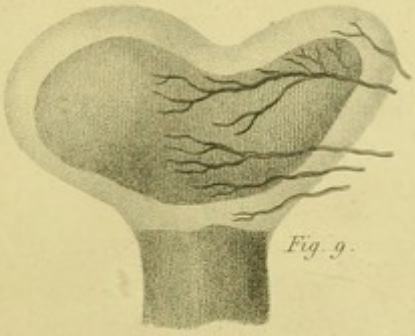

Fig. 10.

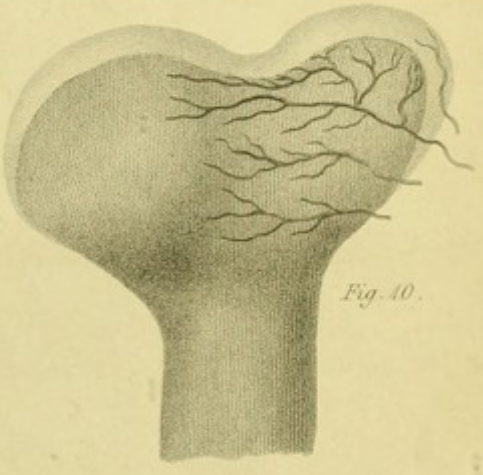

Fig. 11.

Fig 1

Phil. Trans. MDCCCXLI. Plate XIV. p. 190.

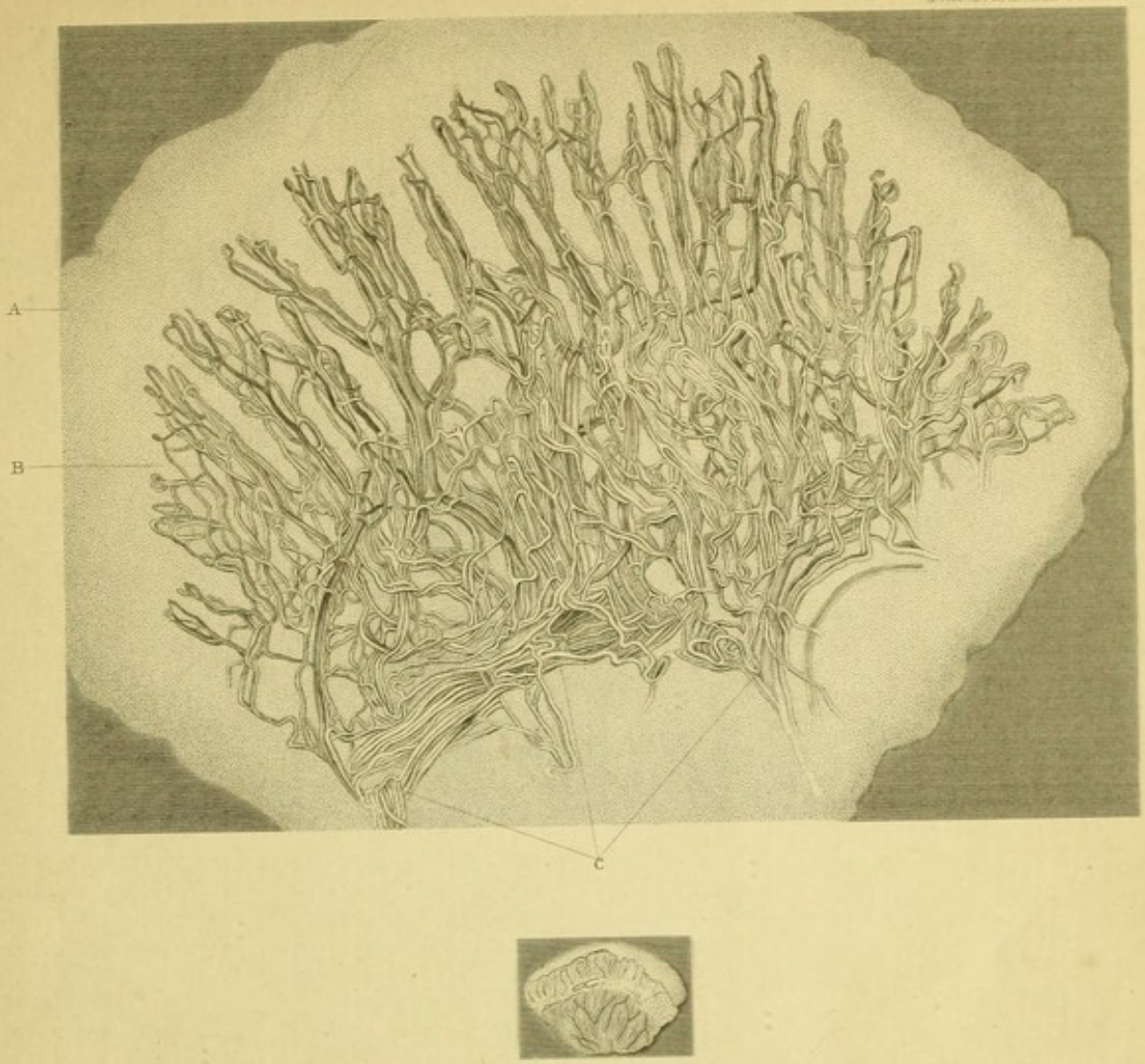

Fig. 2.

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Fig. 1.

Fig. 2.

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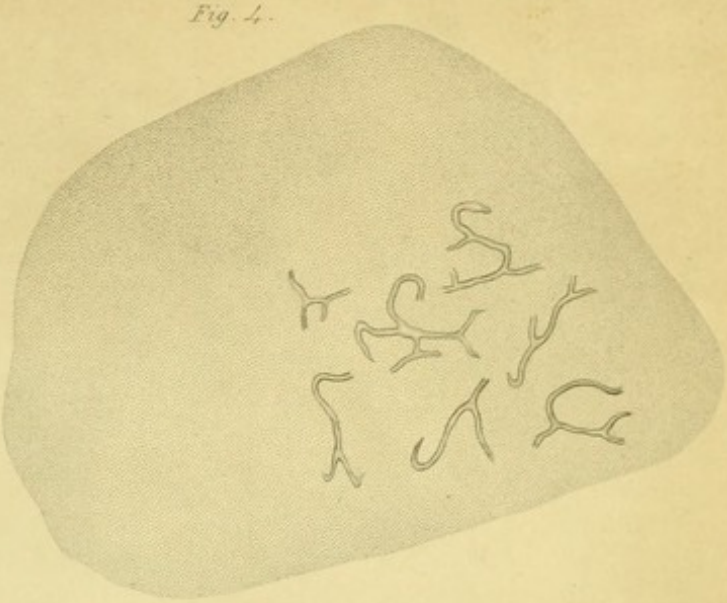
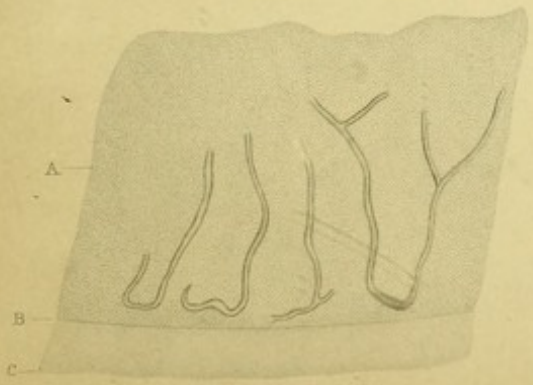


Fig. 6.

Fig. 5.



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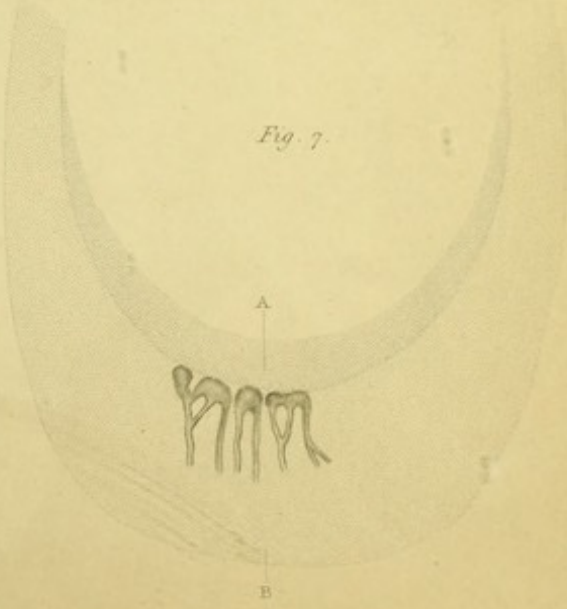

Fig. 1.

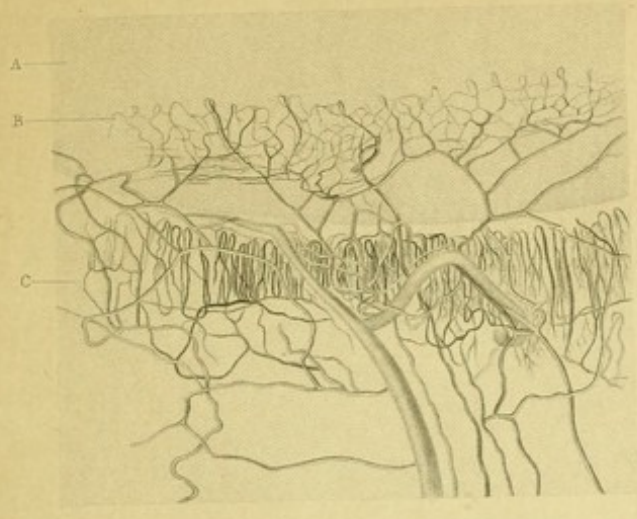

Fig. 2.

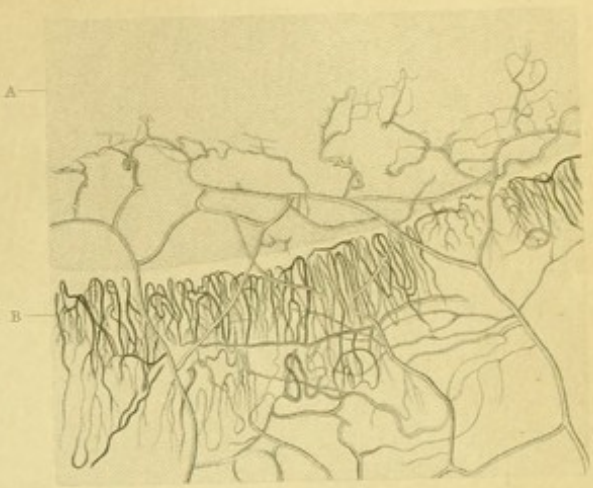

Fig. 3.

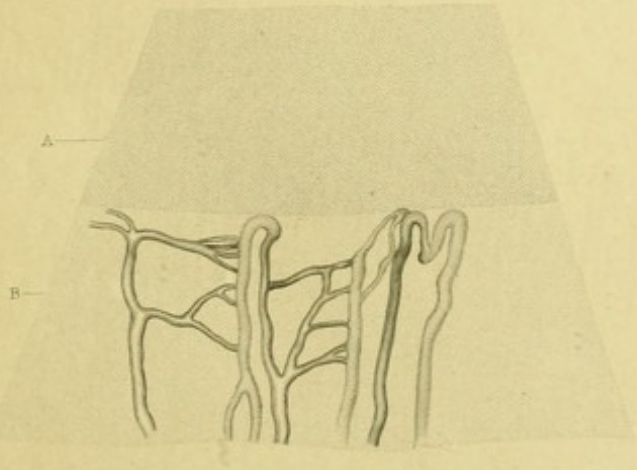

Fig. 4.

Fig. 5.

Fig. 6.