OBSERVATIONS ON THE COMPARATIVE MICROSCOPIC ANATOMY OF THE CORNEA OF VERTEBRATES[1].

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1st. In Mammalia. The cornea is a peculiar modification of the white variety of connective tissue, with certain superadded structures, viz. a structureless or elastic lamella, pigment cells, two layers of epithelium, capillaries, lymphatics and nerve-elements; these structures, in the different divisions of the Vertebrata, vary more or less in their development, in the proportion which they bear to each other, in their arrangement, and sometimes in their intimate structure. As a rule, they are all present, but now and again one or more may be absent.

Until lately the cornea has been considered a structure *per se*, distinct from the tissues surrounding it, and set in the sclerotic as a watch-glass in its frame: that this view was erroneous was pointed out first by Schwann, but was by no means soon acknowledged. I believe that some do not as yet adopt it, though it is very easily shown by a vertical section through the apparent junction of the cornea and sclerotic, when the rounded, confusedly inlerlaced bundles of the latter, with its irregular, stellate, corpuscular elements, will be seen disentangling themselves, becoming by degrees flattened, ribbon-like and tolerably parallel, the corpuscles elongating or rather becoming also flattened, and so in a vertical section showing only, or little more than, their edges. From their lying between the bundles in the cornea they appear in more or less continuous rows.

The relation between the cornea and sclerotic, as far as their optical properties are concerned, is just the same as between the transparent and opaque "troubled" varieties of rock crystal: in each transparency is due to the free transmission of light, in each an arrangement of the component particles, causing reflection irregularly in the substance, and so preventing free passage to light, produces opacity; but I hardly think that this is a difference sufficient to justify the rejection of the cornea as one variety of connective tissue.

Lamellæ of the Cornea.—When a vertical section of the cornea of a mammal is examined, especially if it has been previously dyed, a laminated appearance more or less perfect is seen; this effect is given by a number of longer or shorter very flat ovals, mixed with

[1] This Memoir consists of extracts from a Thesis presented in April 1865 to the Medical Faculty of the University of Edinburgh, by whom a Gold Medal was awarded to the Author in August 1865.

a comparatively small number of long more glassy strips, aided by the arrangement of the corpuscles: the ovals are the transverse and oblique, the strips the longitudinal sections of the bundles. The former present a finely granular appearance, the latter have a glassy look, much resembling the structureless membranes.

The bundles are connected to each other by a gelatinous form of connective tissue, which varies greatly in quantity and consistence in different animals: in the rabbit it is abundant but hard; in the rat it is also abundant, but so soft, especially near the margin of the cornea, that if the conjunctival epithelium be scraped off rather roughly, it is squeezed out of place, and presents much the same aspect as Bowman's corneal tubes, which I believe are generally considered to be the artificial separation of the bundles.

This gelatinous substance is dyed by carmine, though not so deeply as the corpuscles and their processes which lie imbedded in it, yet deeper than the tissue composing the bundles: this last is hardly dyed at all, unless the solution of carmine is very strong; and what it does absorb then is tolerably easy to wash out.

The bundles do not lie on the same plane throughout their whole length, neither do they keep a straight course, but they pass under and over the neighbouring bundles, usually ascending or descending the depth of one or two bundles at a time, seldom more; their lateral curves, in the same manner are not sudden, seldom even approaching a right angle.

The bundles composing the posterior (inner) portion of the cornea are thicker, not so undulating or so tortuous as those forming the middle portion; and these again are far more regular than the most anterior lamellæ. These often present a very interlaced and undulating appearance; this is to some extent a natural arrangement, but often it is greatly increased during the preparation of the section.

This last occurrence appears to me to depend on three things: first, the cornea is part of a hollow sphere, with its parts arranged so as to have equal tension through its entire thickness in that form; when therefore the whole cornea is dried flat on a piece of glass, for the purpose of cutting sections, the outer layers will be relaxed, compared to the inner, and would naturally become wavy, as much as permitted by their attachments. In proof of this, when a third or a quarter only of the cornea is dried, the tension on the posterior layers being taken off, the anterior are allowed more liberty, and when cut into sections, there is generally less waving than in sections cut from the entire cornea.

Secondly, a blunt knife by cutting unequally may also produce it. Thirdly, if in mounting the section the glass cover is pressed down and then pushed to one side so as to produce a rolling movement, the upper surface of the section may be pushed beyond the corresponding part of the lower surface, with the effect of increasing the irregularity.

The two last causes act of course on all the lamellæ, but more on the anterior, because, the bundles being smaller, there are more joints in a given space, and so more capability for motion is also present.

To the same cause is due the milkiness of the cornea after death; the fluids of the eyeball evaporating relax the tension of the cornea, especially of the anterior layers, the ready transmission of light from the one layer to the next is thereby interfered with, and opalescence is produced.

The peculiar transition of the sclerotic to the corneal tissue begins to show itself earlier behind than in front, so that the diameter of the inner surface is rather greater than that of the external, and the sclerotic is as it were bevelled to the inside: in a section of this part, therefore, parallel to the tangent, true cornea is seen to the inside, and true, or slightly modified sclerotic, on the outside. I think that this arrangement is for the prevention of false lights, which would be produced if the glistening sclerotic came close to the line of refraction; as it is, especially when pigment is developed in this situation, it acts as a diaphragm.

It is of course impossible to state with certainty what may be the length of any one of the bundles making up the cornea, but as far as I have been able to make out in the sheep, some of the bundles may be traced in a radial direction, for perhaps a third of the radius, as distinct and separate, then thinning off to nothing, losing themselves amidst other bundles, or dividing in the direction of either their thickness or breadth, and so giving origin to, or joining two or more bundles.

The bundles do not appear to have any special arrangement, but seem to cross each other in all directions, principally at acute angles; some few bundles, especially at the margin of the outer surface in some animals (sheep), seem to be arranged circularly; in man they are arranged radially at this point.

The bundles are composed of white fibrous tissue, the fibres of which are very closely agglutinated, and arranged perfectly parallel to the sides of the bundle, but in the horse some of the bundles have their fibres wavy like ordinary white fibrous tissue, but more flattened.

One great difference between this and other forms of connective tissue is the entire absence of yellow elastic tissue.

The number of bundles making up the vertical thickness of the cornea, in other words, the number of lamellæ, varies greatly in different animals, also, though not to so great an extent in different individuals of the same species, especially with relation to age, appearing to lessen by the union of overlying bundles; as age advances the thickness of the bundles themselves being also increased.

This change seems to begin first in the middle lamellæ, and to proceed to each surface, but it progresses faster with the posterior layers than with the anterior, so that by adult life little difference is perceptible between the middle and posterior layers. I shall have occasion to revert to this again.

Corpuscles of the Cornea.—In the gelatinous substance connecting the bundles are imbedded the usual corpuscles of connective tissue, but they present in this situation a much more regular form than in most others.

In a vertical section they show as elongated "spindle-shaped" bodies, generally with a thickening or nucleus at some one or more parts; it may be with a few processes going off into the surrounding tissue.

In a horizontal section they present an irregular stellate appearance, with numerous branching processes, the principal of which go off in a quadripolar manner; most of these branching processes seem to lose themselves in the surrounding tissues, but the larger ones often appear to anastomose with the processes from neighbouring cells.

Towards the edge of the cornea these become less regular, first of all fusiform, and then identical with the corpuscles of the sclerotic: the superficial cells also in some animals, especially the Rodentia, have a different shape, very little body, but the processes very long, large, and freely anastomosing with each other, in a looping manner, something like the arteries of the mesentery.

They vary greatly in number in different animals, and are far more abundant in young than old corneæ; in fact, the cornea of the human fœtus of between 4 and 5 months' development is almost entirely made up of them alone, and very much resembles the skin of the same age. (Pl. I. fig. 1.)

At this age the greater number are mere oval bodies, not more than one in ten or so having processes, and the intervening substance, the future white fibrous tissue, is hardly present. By the eighth month the corpuscles are large, with several large processes, but with few small ones, the interposed tissue is also fully developed. (Pl. I. fig. 2.) Future changes seem to be, the increase and hardening of the white tissue, the disappearance of some of the corpuscles, and the development on the others of the fine processes.

In the adult cornea, particularly in aged persons, the corpuscles of the middle and posterior lamellæ are few and scattered, while in the anterior layers, where active nutrition is still going on, for the production of the conjunctival epithelium, they are almost as numerous as in the mature fœtus. (Pl. I. fig. 3.)

Are the corpuscles of the cornea "cells"? I believe them to be as much cells as the white corpuscles of the blood; they do not seem to have any distinct cell-wall, but they seem to be masses of a gelatinous substance, "protoplasm" or the "germinal matter" of Dr Beale. This substance contains one or sometimes more nuclei, and pushes out processes into the surrounding tissue; it also seems capable of motion, within at any rate the space it occupies.

The movements which I here allude to are, I think, identical with those performed by the pigment granules in the pigment cell: thus if to a fresh cornea very strong acetic acid be added, and the uncut cornea be then examined so as not to interfere with the corpuscles in any way, the corpuscles appear to be all or nearly all spindle-shaped, and few or no processes are to be seen. If a cornea be then treated with weak instead of strong acetic acid, 8 or 10 drops to an ounce of glycerine, allowing the cornea to remain in for a considerable time, the protoplasm by degrees shrinks and leaves the wall of the cavity, it also becomes transparent, showing its nuclei, while the processes are also often very well seen, the whole then strongly resembling an isolated lacuna of bone.

Now for the same object to take two such very different forms, some kind of movement must have taken place. Recklinghausen describes another kind of movement in the corpuscles of the cornea, of the frog indeed; but what applies to this animal will, I think, in such a matter apply equally to mammals. He states[1], that if a thin section be cut from the cornea as soon as the animal is dead, and this examined, moistened with aqueous humour, and carefully prevented from drying, the corpuscles will be seen pushing out and drawing in their processes, and working their way about in the tissue, actually crossing the field of view.

Kühne also states[2] that "the protoplasm contained in these cells is capable of performing 'spontaneous' movements of an exceedingly torpid character, but gradually changing the form of the cell from the stellate to the fusiform shape, or the reverse."

"The excitation of an interrupted current of electricity, or of sudden changes of temperature, more rapidly effects the alteration in form."

Kühne's observations I consider are well corroborated by my

[1] Abstract in *Syd. Society's Year-book for* 1863.

[2] Abstract in *British and Foreign Med. Chir. Review*, Jan. 1865, page 226.

own; Recklinghausen's I have tried twice, but failed to see what he describes, very likely from inexperience.

Elastic lamina.—The posterior surface of the cornea is lined by a perfectly differentiated structure, easily separated from the rest of the corneal substance.

This structure has gone by a great number of names, such as "Basement Membrane of the Aqueous Humour," "Descemet's Membrane," "Membrane of Démours," "Structureless layer," and "Posterior elastic lamina."

As some of these names indicate, it is a membrane on which the epithelium of the aqueous humour is immediately placed; it presents no determinable structure under the highest powers of the microscope, usually appearing glassy, rarely somewhat granular, it cuts very crisply, sometimes showing a series of longitudinal lines, as if it were made up of very fine lamellæ, at others vertical striations similar to those seen in stiff jelly when cut; it is also very elastic considering its thickness is so small.

This elasticity is shown in two ways. In the first place, it has a strong tendency to curl up with its corneal surface inwards, when separated from the cornea; secondly, when it is cut or pricked it retracts on all sides, making an aperture far larger than the instrument used. It resists the action of most if not all reagents, such as chromic acid, acetic acid, caustic potash and soda, (unless nearly saturated solutions) absolute alchohol, and boiling water; it is deeply dyed by carmine[1]. It is often thicker at the margin than in the centre of the cornea, sometimes indeed very much so.

It is generally described as terminating just outside the margin of the cornea, by dividing into three parts; of these, the innermost passing to the iris forms the "ligamentum iridis pectinatum;" the other two separating from each other enclose the "circular venous sinus" or "canal of Schlemm," and are then lost in the substance of the sclerotic. This account I consider erroneous, firstly, because the cases in which there is a ligamentum pectinatum iridis seem to be the exception rather than the rule, and of these in some I think the process belongs to the iris and not to this membrane; secondly, because I have never as yet seen any sinus in this position. I shall have occasion, when on the vascular arrangements of the cornea, to point out where the venous sinus really occurs.

The true description, I think, would be that it terminates just beyond the margin of the cornea by becoming fibrous, which fibres are lost in the areolar tissue, which is the anterior termination, or point of attachment, of the ciliary muscle. In some animals free

[1] Would Dr Beale for this reason call it "germinal matter"?

processes, either entirely fibrous, or partly fibrous and partly composed of the same structureless tissue as the membrane itself, are sent off from its free surface to the iris, while the greater part goes on and ends as in other animals. There is a remarkable exception to this description in the seal, in which animal at the point of transition of the sclerotic into cornea, a bed of tissue closely resembling tendon on section is interposed between the cornea and the elastic lamina: this bed is thick towards the sclerotic and ends in a rounded form, towards the cornea it rapidly thins and ends in a sharp edge. The elastic lamina sends into this structure five or six digitations, which are sometimes branched and end in slightly clubbed extremities, while a small portion passes on to the areolar tissue in front of the ciliary muscle.

The function usually ascribed to this membrane to maintain the proper curve of the cornea is, I think, an insufficient explanation of its use; for I do not know that it ever forms a $\frac{1}{50}$th of the thickness of the cornea, sometimes $\frac{1}{500}$th, or even less; for example, in the seal this membrane just inside the edge of the cornea is only $\frac{1}{4000}$th of an inch, while in the centre it thins off to $\frac{1}{12000}$th of an inch. Now the cornea of the seal is rather, though not excessively thick. From the habits of the animal it will have to support very sudden changes of external pressure: if then the preservation of the curvature of the cornea depended on this layer, we should expect to find it under such circumstances unusually thick, but it is just the opposite: on the other hand, in the sheep and horse, animals both having very thick corneæ, well able to maintain their own curvature, especially as they have no abrupt changes of external pressure to undergo, this membrane is exceedingly thick.

The means by which the curve of the cornea is maintained, I believe to be the tension of the eyeball, kept up by the due secretion of aqueous and vitreous humours.

Another proof that the development of this membrane is not dependent on the curve of the cornea, may be found in the comparison of the corneæ of the rabbit and guinea-pig: they are both about the same size and thickness, that of the guinea-pig being rather the thinner; they are also about the same curvature, the rabbit being rather the flatter; yet Descemet's membrane in the rabbit is $\frac{1}{1000}$th of an inch thick, in the guinea-pig it is only $\frac{1}{4000}$th.

I think that it may have two principal uses; 1stly, preventing the too rapid absorption of the aqueous humour by the cornea; 2ndly, acting as a tendon to the ciliary muscle.

When I say that it may serve as a tendon to the ciliary muscle, I do not mean that the curve of the cornea is at all altered; tense as is the eyeball in a normal condition, this could hardly be effected by such a muscle as the ciliary; all that I mean is, that it is the point of resistance for the muscle.

Descemet's membrane is much thinner in young animals than in adults; thus, in the human fœtus of from 4 to 5 months it cannot be distinguished; in the new-born kitten it is only $\frac{1}{8000}$th of an inch thick, in the nearly adult cat it is $\frac{3}{4000}$th of an inch thick.

Perhaps this is the best place to speak of a structure, described by Bowman and His, on the anterior surface of the cornea, analogous to the structureless membrane already described. Bowman, who was the first to describe it, speaks of it in the human cornea as a layer from $\frac{1}{1200}$th to $\frac{1}{2000}$th of an inch thick, very like the posterior elastic layer in appearance and characters, but much more intimately united to the proper substance of the cornea, by a series of "fibrous cords" passing down into the anterior layers. To this arrangement he attributes the functions of providing a smooth surface for the support of the conjunctival epithelium, and maintaining the curvature of the cornea.

His states that he has seen it in man, the ox, the sheep, the pig, the rabbit, and the guinea-pig, but not in the horse, goat, dog, or cat.

I believe this membrane, except perhaps in the human cornea, to be an optical illusion, caused in this way. The conjunctival epithelium is of different density and refracting power from the corneal tissue proper; their surface of apposition therefore forms a reflecting surface, from which the light is reflected through the anterior layer; more light in this way is sent through this layer in addition to that naturally passing straight through it, consequently it appears to be more transparent, more glassy than the other lamellæ, especially when not in exact focus. I have seen this appearance more frequently in the cats than other animals, and attribute it to the exceedingly regular manner in which the bundles in these animals are arranged, while in the rabbit, in which the anterior layers are comparatively irregular, and the external surface of the cornea proper not smooth, I have never seen it; but in this animal the corpuscles may occasionally be seen in close apposition to the epithelium.

With regard to Bowman's "fibrous cordage," in most animals (in all that I have examined except man, in whom they are much smaller and more numerous) they are the tracks of nerves. I had long suspected this, but had no proof (among mammalia at least); but fortunately one of my friends lately gave me the eyes of a mountain-hare: one of these I dried on glass and cut sections from, in some of which the "fibrous cordage" was well seen (Pl. I. fig. 4), marked out here and there by rows of yellow-brown fat globules; the other I prepared for the nerves, when I found that they were considerably decomposed, and that many were resolved into the same yellow-brown fat globules as I had seen in the sections. On looking again at the sections, after some trouble I found two or three distinct "nerve-cells," such as I shall describe farther on.

The structure in man to which I have alluded as the only representative of Bowman's "anterior elastic lamina" that I know, is, I believe, a slightly modified form of the cornea itself, not a distinctly differentiated structure: it appears to be formed by the fibres of the anterior bundles of the cornea separating in a fan-shaped manner, inclining to the surface and then interlacing very closely, so that it presents a very finely granular look.

Corneal Pigment.—Just at the junction of the cornea with the sclerotic, and extending a small distance into the former, there are in many animals pigment-cells.

They are arranged in the manner of a diaphragm, projecting into the cornea, farther towards its anterior than posterior surface, and preventing by this disposition the passage of false lights.

They are situated with the cornea-corpuscles in the gelatinous medium connecting the bundles, when very numerous seeming to take their place. In structure they resemble the ordinary pigment-cells, and, like them, show evidence of the movement of the pigment-granules; as sometimes in the same animal they are seen with the processes very dark, while the body of the cell is clear, at others the body of the cell is filled with pigment, and the processes are barely discernible.

In form they may be distinct, or more or less connected together, stellate, fusiform, rod-shaped, or without any determinate form.

They are most abundant where there are vessels, but are wanting in albinos of course, in whom however vessels are present. They rarely project far beyond the capillaries, but I have twice seen them near the centre of the cornea, in which cases they took a comparatively regular stellate shape.

Epithelium of the Cornea.—Each surface of the cornea is provided with a covering of epithelium. The epithelium of the anterior surface is a slight modification of the ordinary epidermic epithelium, prolonged over the cornea from the conjunctiva: it is composed of several layers of cells; of these the deepest are rather elongated, resting on the cornea proper on their ends; the next are about equal in their length and breadth, and from thence to the surface they gradually become more and more flattened, until at last they are nearly as thin as the outer cells of the epidermis; their nucleus however always remains distinctly visible.

This coating varies in thickness in different animals; it is also often thicker at the margin than in the centre. It seems to me that it is the last-formed portion of the cornea, and that it grows over the cornea from the margin, for I have specimens from the new-born kitten, showing it pushed over the cornea about the $\frac{1}{50}$th of an inch, while the rest of the cornea is bare. That it could not have been removed by maceration, is proved by the same section showing the epithelium of the aqueous humour; the other cornea shows vessels and nerves.

The other layer of epithelium is that of the aqueous humour; it is supported directly on the elastic lamina, and consists of a single layer of nucleated cells placed just touching each other, not crowded: they are as thick in the young animal as the adult, but perhaps not quite so large; in the newborn kitten this layer and Descemet's membrane together are about $\frac{1}{2000}$th of an inch thick, of which the membrane forms only about the fourth part.

It has been described as exceedingly perishable; I have not found it so: it may nearly always be found if looked for within three or four days after death; and I have found it in a cornea that had been in spirit for two months, and in a human fœtus that had been dead for a week. The object-glass used has a great deal to do with its visibility.

Nerves of the Cornea.—Although it is thirty years or so since Schlemm discovered nerve-fibres in the cornea, comparatively few observers appear to have directed their attention to them; the only names that I am acquainted with as having published anything about them since Schlemm's discovery, being Rahn, His, Kölliker, Ciaccio, Kühne, and Beale: others, though they did not see them, were mostly content to take the sensibility of this part as an evidence of nerve-fibres being present in it.

It is singular that they should have been so seldom seen, for acetic acid by itself will show them in many mammals and birds, and in some reptiles. The process that I have found most successful is as follows:

Let the conjunctival epithelium be removed from a perfectly fresh cornea very gently. This is best done by acting on it with caustic potash for a time, varying with the thickness of the layer, but the shorter the better; it can then be removed by passing the edge of a blunt knife over it with as little pressure on the cornea as possible. The potash must then be carefully washed away, and dilute acetic acid added, to neutralise any remaining potash, and so prevent it acting on the cornea, and make it take the dye more easily; this is then washed off, and a very weak ammoniacal solution of carmine is put on and left, with occasional stirring, until a light and uniform tint is given. The carmine is then washed away, and strong acetic acid added; the effect of this is watched at very short intervals, and as soon as the nerves are tolerably well seen it is run off, and a mixture of equal parts of glycerine and camphor-water added. The specimen can then be mounted, either in this medium, or, what is in some respects better, in glycerine-gelatine.

If the cornea be very thick it is better not to act much on it with the strong acetic acid, but to put it into strong glycerine to which a little acid has been added, and leave it there for a fortnight or more before attempting to make any sections from it.

If possible, in preparations for the nerves the whole cornea should be mounted in its thickness, for horizontal sections, however carefully made, always destroy a great number of the nerves. When sections are absolutely necessary the cornea should be soaked in glycerine for at least four days to harden it, and then the slices cut with a very sharp knife dipped in glycerine. It is sometimes an advantage to dye them in a solution of the carminate of ammonia in glycerine, after the process of Dr Beale.

The precautions to be observed in preparing the nerves are, 1st, to procure fresh corneæ; 2ndly, not to allow the caustic potash to act so long as to reach the cornea proper, as it at once destroys the finest fibres; 3rdly, to use the cornea throughout with the utmost gentleness; 4thly not to dye too deeply; lastly, not to act too long with the strong acetic acid, as it disintegrates the nerve-fibres.

I have succeeded sometimes in displaying the nerves by the use of a magenta dye, but it seldom does so well as carmine, and very soon fades away.

If a cornea cannot be mounted at once it may be preserved for some time in the strongest glycerine: I have mounted some tolerably successfully which had been kept for two months. Spirit does not do well; it soon makes them granular, and if they are fine destroys them.

The nerves of the cornea seem to be derived from the ciliary nerves alone; though I do not say positively that none come into it from the conjunctiva, yet I have never seen any in spite of many trials.

The ciliary nerves pass forward in the grooves in the sclerotic. When they reach the ciliary muscle they divide into two sets of branches, one of which goes to supply this muscle and the iris, the other set passes yet more forward and is distributed to the cornea.

This set may again be divided into two, the superficial and the deep; of these the superficial are usually much smaller and pass outwards to the surface, dividing as they proceed. When they reach the margin of the cornea they are very near the surface, all being contained in the anterior fourth of the thickness, and the trunks are few, composed of more than two fibres, and by far the greater number are entirely resolved into single fibres.

The deep set are much larger than the superficial, and do not divide so much, so that they reach the margin of the cornea still as large trunks: their place of entrance is about the middle of the thickness, occupying perhaps the middle third.

No fixed number of nerve-trunks appear to enter the cornea, though Dr Ciaccio seems to consider that each animal has a definite number; but, according to my observations, they vary, not only in different animals of the same species, but in the two corneæ of the same individual, both inversely to the number of fibres in the superficial layer, and to the size of the trunks themselves; for when these are large the number of trunks is small. Having reached the cornea the trunks become excessively hyaline, from the loss of the white substance of Schwann, of which only a very thin coating can be seen, just after the entrance of the nerve; it also disappears very shortly; many of the fibres are without even this, and the solitary superficial fibres are entirely without it, being reduced to the axis-cylinder and a prolongation of the membrane containing the white substance of Schwann.

The number of fibres composing the trunks varies greatly, from 2 or 3 up to 20, or perhaps in some animals more, but it is impossible to say, from the size of a trunk, what number of fibres it may contain, for the fibres become imbedded in much the same kind of gelatinous substance as that connecting the bundles of the cornea, and this varies greatly in amount, and also fibrillates under the action of acetic acid. Thus I took notice of a trunk in the cornea of a dog, after I had removed the epithelium, and saw distinctly that it contained three fine dark bordered fibres, well separated from each other; after tinting and treating with acetic acid, the same trunk looked as though it contained 10 or 12 fine non-medullated fibres, but its distribution only showed three fibres.

The trunks do not enter the cornea at regular intervals; they are, I think, rather more numerous at the sides of the cornea than at the top and bottom, often also a comparatively large part of the circumference may be found, without any entering trunk; a large trunk near will then be found to bend aside, follow the curve of the margin, and, giving off branches from its concave side, supply the deficiency.

Sometimes a trunk immediately on entering sends off a branch to a neighbouring trunk (generally a weak one), which thus reinforced, passes on to its distribution, or a trunk may divide into two parts, and both join other trunks.

Having entered the cornea, the fine superficial nerves at once begin to be distributed, by forming a polygonal meshwork between the bundles composing the 3 or 4 anterior lamellæ, occasionally coming right to the surface so as to be covered only by the epithelium.

This meshwork is more or less close according to the animal, and is formed by the division and union of the fibres; at nearly every, I believe at every, point of division or junction there is an enlargement, usually triangular, but often quadrangular or multangular, according to the number of fibres meeting at that point.

These enlargements I consider to be true nerve-cells, in fact, they bear a strong resemblance to the cells of the spinal cord; they were first seen, I think, by Ciaccio, and were called by him "peculiar bodies." In structure they consist of an investing membrane continuous with the membrane of the fibres, and contents, which during life perfectly transparent, are coagulated, and rendered granular by reagents.

If the specimen has been successfully prepared a vesicular nucleus may be seen in many, often in one of the angles (Pl. I. fig. 6); occasionally two nuclei are met with, particularly in those cells that have more than three angles; they appear sometimes to contain also a little pigment.

The cells are exceedingly thin, and are placed usually parallel to the surface of the cornea, not often at right angles or very obliquely.

The superficial nerves forming the meshwork pass inwards for perhaps half the radius, meanwhile the deep trunks passing in form also a network, but a very much coarser one than the superficial, and as they pass in, they proceed towards the anterior surface of the cornea, which they reach somewhere about the middle of the radius.

The network of the deep nerves is formed in a different manner to the superficial meshwork; the trunks divide usually by the mere separation of their fibres into two or more smaller trunks, which in their turn divide until the fibres become single; the branches of one trunk often unite with those of another.

Occasionally, in some animals frequently, one of the fibres of a trunk, at a point of division, is connected with a large nerve-cell, and sends a fibre along each trunk. The solitary fibres also pass into large cells where they divide, the fibres going off being generally smaller than the fibre joining the cell, and also generally going to the surface.

These large cells are the same in structure as the smaller ones belonging to the superficial set, but they are very usually polyclonic; an irregular triangular pyramid is not an unusual shape, but they may have six or seven poles; they are also much thicker than the small nerve-cells, and are often placed vertically.

By the time that the deep nerves reach the anterior lamellæ, about the middle of the radius, they are reduced to nearly the same size as the superficial nerves; these they then join by means of the nerve-cells, and they together carry on the meshwork to the centre of the cornea, the nerves from all sides helping to form the meshwork here.

Throughout the whole of this meshwork no free ending of a nerve-fibre is ever found, at least in a well-prepared cornea; moreover, nerve-fibre always passes into nerve-fibre through the medium of the nerve-cells; they certainly never become connected with the cornea corpuscles. Ciaccio was the first to point out this distinctly, nevertheless Kühne has lately written as follows: "Near the centre of the cornea the axis cylinder becomes very pale, varicose, and connects itself with one of the caudate prolongations of the stellate cells[1]."

I think that Kühne's own words show why he fell into this mistake; he describes the nerve-fibre as "varicose;" I suspect from this, that he examined either corneæ that were not fresh, and consequently the nerves partly disintegrated, or sections and specimens which had been too roughly used.

A properly and successfully prepared fresh cornea shows the nerve-fibres between the cells almost like fine threads of glass. My own observations in respect to the relation of the fibres to the stellate cells fully bear out Ciaccio's statement, that "the only relation the nerve-fibres bear to the corpuscles of the cornea is that of contiguity."

I have said that I believe that at every point of division of one fibre, or of junction of two or more fibres (by junction I mean not mere apposition, but the actual fusion of the one with the other), there is an enlargement which from its structure and aspect, as well as from its connections, I regard as a true ganglionic nerve-cell. Their universal presence has, I think, not yet been recognised; for Ciaccio, the most recent writer on the subject, though he recognises their occurrence, seems to regard them as comparatively rare, and figures nerve-fibres dividing without any enlargement whatever. I believe him to be wrong here, because, seeing their presence so very general, I was induced to re-examine the apparent exceptions, and I found that with higher powers I could see many cells that had escaped me before, particularly as my eye became educated.

Still there were some that defied all means to demonstrate a cell; but I think that these may be explained, some by the cell being vertical instead of horizontal, others by two fibres running in close contact, and then separating.

I may remark, that a lens with a large angular aperture is of

[1] *British and Foreign Med. Chir. Review*, Jan. 1865, page 226.

considerable advantage, when the fibres are fine, and when the cells are very hyaline, a $\frac{4}{10}$th of 55° showing many of both that a $\frac{1}{4}$th of about 38° could either not show at all, or but faintly.

Very large polyclonic cells are sometimes seen in the superficial meshwork; these may perhaps be formed, sometimes at any rate, by the coalescence of two or more ordinary cells with three or four poles. I have a specimen from the rat showing a large cell with five fibres going off from it, and a large oval hole in the middle, showing evidently that it is composed of five triclonic cells. (Pl. II. fig. 1.)

In the large triclonic cells of the deep nerves, where a tolerably thick trunk appears to merge itself in a single cell, and to give off only two fibres, is this to be taken as evidence of there being only one fibre in the supplying trunk? In other words, can two fibres of the same trunk go to form one cell in that trunk, and have only two fibres of distribution?

I have seen, on one occasion, in the guinea-pig a large cell, with apparently but one fibre passing to it from the periphery of the cornea, whilst two fibres proceed from it towards the centre of the cornea, each of which soon divide with an ordinary cell at the point of division; yet the granular contents of the large cell were distinctly divided into five masses, each of which almost seemed to have a nucleus.

All the fibres given off by one of the ordinary cells of the superficial meshwork are pretty nearly equal in size; but occasionally we meet with a cell, one or all of the fibres of distribution of which are very much finer than the ordinary fibres, a fifth to one-tenth the size. These fine fibres it is difficult to trace for any distance, seldom even to a distinct termination of any kind: very rarely indeed I have succeeded in tracing them to another cell, either to an ordinary one, or to one bearing the same proportions to an ordinary cell as these fine fibres do to the other fibres.

These fibres and cells I am at present inclined to consider as atrophied, their functional life being ended; but they may prove possibly to have some relation to another system of nerves, which I shall mention farther on. Connected with the trunks, especially with the larger ones, may be seen a few small fusiform nuclei, which appear to belong, most of them at least, not to the nerve fibres, but to the tissue they are imbedded in: they become rarer and rarer as the trunks become smaller, and in the superficial meshwork are very scarce.

I have never seen the nerve-fibres in the meshwork with any nucleus involving their substance; very rarely a small nucleus may be seen adherent to the one side, but the fibres themselves pass from cell to cell, round and highly refractive, maintaining a tolerably equal diameter throughout.

These nerves are, I believe, nerves of ordinary sensation, and such has been the general opinion of observers with one exception, Dr Beale. This gentleman, in a paper published in the *Micros. Journal for* 1864, page 13, considers them to be capillary nerves, and that they only convey sensations of pain in morbid states of the cornea, usually influencing the nutrition of the cornea. Now I do not deny that they may influence nutrition, but if they do so, the power must be extended to all other nerves of ordinary sensation; and that these are such I think is shown by the great pain produced when a small portion of the corneal epithelium has been scratched off. There is another set of nerves in the cornea much more closely resembling Dr Beale's "capillary nerves," and such I believe them to be; to these I now turn.

Among Dr Beale's numerous observations on nerves, he has described a plexus of excessively fine, non-medullated nerves, ramifying on and among blood-vessels, even to the terminal capillaries, illustrating his observations by reference to the palate of the frog. In the course of my study of tissues in general, I repeated his observations, confirming them as far as I could with the powers at my command; and then turned to the cornea, in which, first in the sheep, and soon after in the rat, after some time I found nerves around, and in the immediate neighbourhood of, the capillaries, in essential particulars bearing a close resemblance to those in the palate of the frog.

In the rat these nerves are very distinct in appearance from the ordinary nerves before described, and present a great contrast in size, the ordinary nerves average in diameter from $\frac{1}{6000}$th to $\frac{1}{8000}$th of an inch, while the capillary nerves average from $\frac{1}{16000}$th to $\frac{1}{21000}$th of an inch, some running so fine I believe as $\frac{1}{30000}$th, though I never was able to get a good measurement of them, one I could rely on, with the micrometer I use. (Pl. II. fig. 2.)

In the sheep they are much more numerous than in the rat, from the capillaries being so much more numerous; but the distinction between them and the ordinary nerves is less obvious owing to the much greater fineness of these last compared to those of the rat, while the capillary nerves are of about the same diameter. (Pl. III. fig. 2.)

Perhaps a better name for these nerves will be tissue nerves; for they occur in the tissue surrounding and at some distance from the capillaries, as well as in their immediate neighbourhood.

These nerves follow much the same arrangement as the ordinary nerves, in their terminal plexus.

A moderately thick fibre ($\frac{1}{5000}$th of an inch in diameter say) enters the cornea in the neighbourhood, and on a level with the capillaries; it is usually single. Once I have seen one separating from a trunk of ordinary nerves; sometimes it enters in close proximity to the vessels, but these are usually surrounded by fibres already forming their terminal plexus.

From this it will be seen that, like the sensor plexus, the meshwork formed by these nerves is supplied from two sources, namely, nerves that have already become functionally active, (for I consider that a nerve is not functionally active until it has reached its terminal expansion,) in the sclerotic, and nerves that enter the cornea before they become so. These last very soon on entering the cornea become connected with a cell, the fibres which go off from this are perhaps $\frac{1}{12000}$th to $\frac{1}{16000}$th of an inch in diameter, and very likely each divides again, and then joins the plexus of nerves that have already divided, ramifying above, below, and around the capillaries; also in the space of the loop, many pass beyond the limits of the capillaries, continuing to form a plexus for some distance, but one with more open meshes. Finally, this plexus seems to send off long comparatively straight fibres, which may be sometimes traced a long way, being at last lost sight of; sometimes they seem to terminate in the cells of the sensor nerves.

Whether this appearance be a deception or a fact, and whether the very fine fibres, which I have mentioned as occasionally seen among the ordinary fibres, have any connection with these nerves, I am not prepared to say. The meshwork formed by these nerves is supplied at the points of division and union with cells proportioned to the diameter of the fibres, so that the cells of the first and second division frequently show their nucleus; but in the majority this cannot be seen, especially the very small cells that may be found on the curious sheath which the capillaries possess.

My reasons for regarding these nerves as distinct from the nerves that have been before described, may be gathered from what I have said. They are, briefly, difference of size in fibre, cell, and mesh, and difference in position, being so very abundant round the capillaries; in fact I have only seen them numerous in animals that have the corneal capillaries very well developed, to wit the sheep and rat.

I believe them functionally to be referable to the vasomotor system, taking this name in a wide sense; for as capillaries are not considered usually to be actively contractile, and if they are, as these nerves are distributed beyond the capillaries, it would be absurd to call them vasomotor in a strict sense; in other words, I would transfer Dr Beale's idea of the function of ordinary nerves to these, or to part of them, and attribute to them the office of influencing the nutrition of the cornea, in a reflex manner acting on the vessels supplying it.

Vessels of the Cornea.—The vascular arrangements of the cornea consist of capillaries and lymphatics, which bear a very intimate relation, the one to the other.

The blood-vessels are capillaries only, large and small; I have never seen an artery passing into the true cornea. In most animals the ciliary and sclerotic arteries are the source of the whole supply; but in the horse, dog, and perhaps man, a few capillaries pass in from the conjunctival vessels.

The capillaries form round the margin of the cornea a network of loops, with the convexity of each loop towards the cornea: they vary greatly in their development; some animals have no capillaries in the true cornea, the loops occurring in the transitional portion between the cornea and sclerotic; while others send single loops, or large compound tufts, far into the cornea, every gradation being found between these extremes.

The capillaries usually pass into the cornea at about the fourth of the thickness of the cornea from the front, and in many animals this is the only place of entrance; but in others a few also enter just in front of the elastic lamina, and in very thick corneæ also between these.

In the many healthy corneæ I have examined, I have never seen the capillaries passing farther into the cornea than perhaps one-fifth the radius.

Even the human fœtus of the 8th month shows no sign of capillaries farther than the adult; and the new-born kitten, with its capsule of the lens and *membrana pupillaris* beautifully vascular, shows the capillaries of the cornea ending in loops a little inside the margin as plainly as the full-grown cat.

The blood passing from the cornea is collected by large capillaries, and poured into a large vein that surrounds the cornea at some distance outside its margin. (Pl. III. fig. 1 *a*.) This is the circular venous sinus of Schlemm: it occurs at about one-third the thickness of the sclerotic from the outside, not, as it is often described, where the elastic lamina loses itself; an artificial separation is very easily made in this situation, which has, I suppose, given origin to the idea of the sinus being in this place.

The blood from the sinus is carried off by four or five large veins which pass backwards in the substance of the sclerotic, join the choroidal veins, and then emerge. (Pl. III. fig. 1 *b*.) In structure these capillaries resemble others, consisting of a membrane with scattered nuclei, well shown by caustic potash; their walls are not attached to the corneal tissue, but they are quite free (the greater number at least) to swell out and collapse, according to the amount of blood contained in them, as will be shown in the description of the lymphatics.

When the cornea is irritated, capillaries are frequently formed, which afterwards atrophy, and they atrophy in this manner: the vessel contracts at the loop, and at last is obliterated; and the contraction progresses along the two capillaries forming the loop, so as gradually to shorten them, the free ends thus formed being pointed; beyond the point and along the sides of the vessel the corpuscles of the cornea are seen to be altered in form, being fusiform, and larger than usual; the capillary itself is of greater diameter than the ordinary ones. (Pl. II. fig. 3.)

I had long been looking for lymphatics in the cornea without success. I had also long been familiar with an appearance round the capillaries of the cornea of the rat, resembling a very loose nucleated sheath, which I regarded as a sort of channel in the corneal tissue, larger a good deal than the vessel, so as to allow the vessel to dilate and contract freely, according to the amount of blood needed by the cornea, which of course being a firm hard tissue would not admit of ready dilatation, if the vessel were immediately in contact with it on all sides. (Pl. II. fig. 2.)

Some time after I first noticed this appearance, I was examining the cornea of a rat, from which I had partly removed the epithelium, and in it I noticed large rounded vessels forming loops at the margin, in the same manner as the capillaries usually do in that animal: these vessels appeared full of a fluid containing a good deal of granular matter, and a few colourless round cells, I naturally at once set them down as lymphatics. Unfortunately I made no drawing of them in this state, thinking that they would be plainer when fully prepared; but in the subsequent manipulations most of the contained fluid was forced out, and they then presented the appearance I was already familiar with, with the exception of two or three loops, which still kept some of their granular contents, but had no capillary inside. If these were lymphatics, what relation did they bear to the capillary? They had not the appearance of accompanying the capillary as the *venæ comites* accompany an artery, and no division, or fenestration, was seen such as Dr Carter has described (*Medical Times and Gazette*, September 1864) in the arrangement of the lymph-vessels accompanying the arteries of the liver. Neither could it be said that the lymphatics were simply superimposed on the capillaries. The most probable explanation of the appearance was that the capillary was enclosed within the lymphatic.

This explanation I was very unwilling to adopt, as I had never heard such a relation mentioned, and I did not see how nutrition was to go on, according to the ordinary ideas; also, though I examined a great number of rats and other animals, I never again saw the same appearance of large vessels filled with granular fluid. I began to think therefore that I had been mistaken in calling them lymphatics, and to revert to my original idea of a sheath, and to consider that the appearance might be due to the cornea (though it seemed perfectly normal) being in an incipient state of inflammation, and so exudation poured out into the sheath. A little after this, while examining the nerves, which I have described as capillary or tissue nerves, in the sheep, I was struck by the frequency with which rows of rounded nucleated cells occurred along one or both sides of the capillaries. (Pl. II. figs. 5 and 6.) These bodies were smaller and more regular in shape than the corpuscles of the cornea, moreover they possessed no processes; and a membranous sheath similar to, but not so strongly defined as that in the rat, was also usually seen enclosing them.

At the root of the tuft of capillaries the same rounded bodies were seen often, in very great abundance, surrounding the capillaries; but occasionally a large vessel, two or three times the size of a capillary, with excessively thin walls, was to be seen, not enclosing any blood-vessel, but with a considerable number of the same bodies in it; in fact, but for these cells, the vessel would have been almost or quite invisible; very usually the cells were collected in the vessel in a mass, crowded and rounded towards the cornea, scattered towards the sclerotic (Pl. II. fig. 5 *b*); beyond the mass the vessel might with great difficulty be traced a little way, but from its excessive tenuity no determinate end could be made out, though it often seemed to go on to a capillary and join the sheath.

The round bodies or cells seen in these situations precisely resembled the white corpuscles of the blood, in size, in being nucleated, and in being granular and rough. I connected this appearance with that which I have just referred to in the cornea of the rat, and regarded it as additional evidence in favour of the view that the capillaries were enclosed within lymphatic spaces. Shortly afterwards my attention was directed to a paper by Professor His (*Siebold und Köllikers Zeitschrift* 1865) in which he describes "perivascular spaces" surrounding the vessels of the brain and spinal cord, which he was able to inject, and from them to fill the lymphatics of the meninges. This observation gives me additional ground for believing that the arrangement I have described in the cornea must be referred to the lymphatic system. I have also tried to inject these vessels, but from the unfavourable nature of the tissue in which they lie, have only once succeeded, and that to a very limited extent; but I consider the evidence afforded by the presence of lymph-like corpuscles in them better than any injection. I have seen similar arrangements in every cornea that shows the vessels, in the mammalia and birds, also in the iris of the pigeon. (Pl. IV. fig. 1.)

I believe the lymphatics do not terminate in the same way as the capillaries. Not unfrequently in the rat an offset may be seen stretching beyond the capillaries into the cornea, and being lost there; also long, straight, structureless fibres may be sometimes seen passing from them across the cornea, from which other shorter fibres spring at right angles; these, from a specimen which I have from the pigeon, I believe to be lymphatics without contained capillaries.

These vessels seem to have an exceedingly fine membrane with a few scattered nuclei, as their sole constituent; it is attached to the corneal tissue pretty firmly, but still is free enough to fall into folds when relaxed.

In calibre they vary very much; when the capillary is fully distended with blood in the sheep it nearly fills it, leaving perhaps a quarter vacant; in the rat they are very much larger; they may often be found in the sclerotic.

When capillaries are developed anew by irritation, the lymphatics are also developed very largely, especially the free trunks.

If the nerves, that ramify plentifully in the outer portion of the sclerotic coat of the human eye-ball and the lax areolar tissue on it, are carefully examined, peculiar rounded or oval bodies will be seen connected with them, hanging on to them like a cherry on its stalk; for at the first glance but one fibre can usually be seen, going to each, but with a power of 400 or more diameters, several additional fibres often come into view. (Pl. V. figs. 2, 3, and 4.) These bodies I believe to be ganglionic nerve-cells, similar to those described by Dr Beale from the sympathetic in the abdomen of the frog; I also think that they are nerve centres belonging to the "vasomotor" system, taking this word in a wide sense and making it include the motor nerves proper and the tissue nerves.

My reasons for this opinion may be gathered from the following short account of them. They are rounded or rather spherical bodies, varying in size from $\frac{1}{500}$th to $\frac{1}{2500}$th of an inch in diameter, possessing a membrane which is very lax and wrinkled, which also shows a few nuclei; the contents appear to be granular, and a central more opaque portion is often visible.

The larger cells have usually one nerve-fibre possessing a medullary sheath going to them, which generally loses its sheath of white substance a short distance from the cell and proceeds as the axis cylinder alone; the smaller cells have usually no such fibre.

In addition to the dark-bordered fibres the larger cells have one or more, frequently four or five, very fine fibres passing away from them; these are nearly always arranged in a spiral manner to each other and the large fibre. They are often nucleated, and sometimes divide dichotomously, with a small triangular enlargement at the point of division.

Generally all the fibres pass from the same end of the cell, but sometimes when the cell is oval or very large, a few pass from the opposite end as well.

In the small cells fine fibres alone are as a rule to be seen.

The fine fibres may accompany the large fibre, and join the nerve-trunk it comes from, these trunks being generally composed of dark-bordered and fine fibres, or they may pass to their distribution as an independent trunk of fine fibres alone.

Now these fine fibres, when they can be followed to their distribution, are found to form a plexus, similar to that seen in the skin of the frog, in the palate of the same animal, and also to that of the tissue nerves of the cornea. These bodies are to be found as far forward as the ridges surrounding the margin of the cornea, here they are of the smallest size with only fine fibres; I think it not improbable that those found in this situation may be connected with the tissue nerves of the cornea itself.

It might be suggested that these bodies were "tactile corpuscles," but their structure does not resemble that of the touch bodies I have seen nor yet of the Pacinian bodies; moreover, the touch bodies occur in papillæ, and in parts that are used for touch, not in parts where the perception of pain is all that is necessary.

I may say, as making my opinion of their nature more stable, that I have seen, in immediate connection with the larger nerve-trunks in the palate of the frog, cells identical in appearance with those found in the abdomen of this animal. I have as yet seen these structures in man only.

2nd. In Birds.

The cornea in the majority of birds presents an entirely different aspect to that of mammals. In a vertical section it seems like a single thick lamina of a slightly granular substance, with a number of fusiform corpuscles imbedded in it; this is the appearance shown by birds such as the swallow, thrush, titmouse, finches, wren, robin, magpie, lark, parrot, &c. (Pl. IV. fig. 2.)

In the Raptores the cornea is much the same as in mammals, being composed of tolerably large bundles arranged at right angles to each other, and interlacing very regularly as if woven; the corpuscles are numerous and are placed very uniformly among the bundles, which are very thick in proportion to their breadth. (Pl. IV. fig. 1.) I think that the cornea of other birds is formed exactly in the same manner, but the bundles are very small and closely united, while the corpuscles are not so numerous and are arranged in an entirely different manner.

In those birds first mentioned the corpuscles are small, on a surface view round, with several branching processes, which show a tendency to a quadripolar arrangement: in a vertical section they are seen to be arranged in two principal layers, the thickest of which is near the anterior surface, close to it in some birds, as the starling and wren; with a more or less broad band of corneal tissue, void of corpuscles, between it and the surface in others, as the swallow, linnet, magpie, parrot, &c.: this anterior layer of corpuscles often occupies $\frac{1}{4}$th of the thickness of the cornea.

The thinner layer is immediately in front of the elastic lamina, it often consists of only two layers of corpuscles, sometimes of only one, as in the robin. Between the two layers are found only a few scattered corpuscles, the comparative number varying greatly; there are but one or two in the lark, while they are rather numerous in the parrot.

In the Raptores there is none of this grouping of the corpuscles; they are more numerous in the very anterior layers as in mammals, but they occur uniformly, and very plentifully throughout the rest of the thickness of the cornea; in these the vertical section hardly shows any processes to the cells, in the other birds plenty may be seen.

There is the same change from sclerotic to cornea in birds as in mammals, but in the small birds it is very abrupt and often not very clear; in the eagle, on the other hand, it is as distinct as in mammals.

Descemet's membrane is always present, but is exceedingly thin; in the eagle it is but $\frac{1}{8000}$th of an inch thick, and in most birds not half so much; in fact we should usually not be able to recognise its existence at all, but for the way in which it is thrown into folds when the cornea is laid out flat; it passes entirely to the areolar tissue on the inside of the sclerotic, never providing the iris with a ligament.

The conjunctival epithelium is always well developed, the cells often show their nuclei very clearly: the epithelium of the aqueous humour is not often seen.

The cornea of birds, especially of the smaller ones, is most plentifully supplied with sensor nerves; they are very distinctly divided into a deep and superficial set, and are much finer than the same nerves in mammals, the most superficial being frequently as fine as the tissue nerves in the sheep, though, owing to their much greater refracting power, and to the transparency of the cornea, they are far more readily seen, and they are also less interfered with by the corpuscles.

The general description of the sensor nerves already given under the mammalian cornea answers very well for those of birds; but the meshwork is more irregular and closer, the cells very seldom show any nucleus, and many places of division, or of apparent division, are visible, which show no indication of an enlargement. The small size of the nerves, and their much more frequently ramifying in a vertical direction, (as seen in sections) may I think account for much of this last difference.

I have said that the superficial nerves are very fine; they are also very near the surface, consequently they are very often destroyed; and until lately I was ignorant of their existence, having mistaken the meshwork between the deep nerves and these superficial ones for the terminal plexus, as these intermediate nerves are both fine and abundant.

The same method answers for the preparation of the nerves of birds as for those of mammals; but very great caution must be used with the potash and manipulations.

The nerves vary in development in different birds; they are strong and numerous in the finches, not so strong but more numerous in the lark; comparatively few in the wren, titmouse, magpie, &c.: in the eagle they are tolerably numerous, the fibres fine, the cells small, the meshes large, and very usually more or less regularly rectangular.

In birds, generally, the large trunks enter the cornea often very near the posterior surface, and do not reach the surface until the centre of the cornea.

Capillaries are very seldom seen. As a rule they do not extend beyond the pigment, which surrounds and hides them; when they are visible they are seen to have a very thin coat indeed, and are arranged in a very close and intricate network, each capillary sheathed in a lymphatic, which is very distinct when the capillary is only moderately distended. (Pl. IV. fig. 3.)

I have only seen capillaries in the pigeon, eagle, greenfinch, and titmouse, in these two latter only once out of many corneæ; the pigeon is far the best to examine, in it many of the capillaries form little loops of a single capillary twisted on itself and standing up free into the conjunctiva; these show the lymphatics very plainly, as when looked down on, each loop looks like an oval cell with two strongly defined round nuclei, merging into a single indistinct oval one when the top of the loop is brought into focus. (Pl. IV. fig. 3 *a*.)

I have also seen in the pigeon, in the cornea itself, narrow vessels with very ill-defined walls filled with granular matter; they occur as a group arranged in a rectangular manner lying at some distance from the edge of the cornea, a single larger vessel leading away from them to the edge of the cornea, where it joins another group of similar vessels; there are also a few isolated portions as it were around the edges of the first group. I am inclined strongly to look on these vessels as lymphatics; but whether this is the normal arrangement accidentally engorged, or a pathological production, I am not prepared to say; but at present I regard the former as the more probable.

I have never seen any tissue nerves in birds.

3rd. In Reptilia.

Of this class I have only examined the tortoise. My remarks, therefore, will be confined to this animal.

The general structure of the cornea of the tortoise is between that of mammals and fish; the lamellæ are thin and well marked, the corpuscles small and few, but pretty regularly scattered through the whole thickness. The bundles are very broad, and have almost lost their individuality, blending with their neighbours by their margins; they are also arranged, as in birds, at right angles to those that occur immediately above and below them.

I have never seen the corpuscles other than fusiform; and they also are arranged principally in two directions, one at right angles to the other.

The sensor nerves are very large and strong, with the cells well marked, and pretty numerous. (Pl. III. fig. 3.) The Greek tortoise has many more nerves than the box tortoise; but they are larger in the latter, especially the cells. In the latter also the deep trunks are large; in the former a trunk is a rarity.

The pigment-cells do not form a regular border to the cornea, but occur as groups pushed in here and there; in the Greek tortoise these groups are moss-like in appearance; in the box tortoise they are in the form of distinct fusiform cells crossing at right angles. The capillaries are few but very large, forming a network something like that in birds, but simpler; I have not been able to distinguish any investing lymphatic, but it by no means follows that they do not exist, as my specimens are unfavourable.

Tissue nerves I have not seen in the reptilia.

4th. In Batrachia.

In the frog, the only animal of this class I have had an opportunity of examining, the structure of the cornea is precisely similar to that of the tortoise, except that Descemet's membrane is nearly twice as thick, that is $\frac{1}{8000}$th of an inch.

The conjunctival epithelium is very beautiful, the cells distinct, and the nucleus very evident.

The corpuscles are rather larger than those of the tortoise, and very often look as if fusiform; but their real shape is stellate, as is very well seen in a cornea acted on with nitrate of silver during the life of the animal.

The sensor nerves I can say little about, for they are very difficult to bring out, and none of my preparations being really satisfactory, all that I know at present is that the trunks are very large, the fibres fine and very loosely arranged in them, and that they anastomose as trunks of considerable size, forming a coarse network all over the cornea; at the points of division or union there are sometimes, I think, to be seen triangular cells connected with one of the fibres, but they are very difficult to make out: Ciaccio describes them in this situation: the fibres sometimes appear to divide in the trunk with very small enlargements, they also leave the trunk as single fibres; but I have been unable to trace them far from the place of departure, and so know nothing of the terminal expansion.

Pigment is very abundant round the cornea, the cells being very irregular, with short thick processes.

Capillaries are very sparingly supplied, and I have never seen them beyond the pigment, so that any lymphatic there may be is hidden, but the vessels of the sclerotic show the investing lymphatic tolerably well.

Tissue nerves I have not seen in the cornea, but they are plentiful in the sclerotic.

5th. In Fish.

In this class my observations have been almost confined to the cod and conger eel.

In fish the cornea (taken in a wide signification) is in appearance an entirely different structure to that of the previously described classes; there is no conjunctival epithelium; instead, the skin of the body passes over the eye, and is modified into a structure closely resembling cornea, being made up of fibrous layers laid down at right angles to each other, with corpuscles between them. It is united to the cornea proper by a very soft, gelatinous, mucus-like connective tissue, which in the cod is very distinct, less so in the conger eel, and hardly to be seen at all in the trout. In the cod it is divisible into two layers, the inner of which is thinner, softer, very full of oil, and not so firmly laminated as the outer.

The true cornea is attached to the sclerotic, and is a modified form of it, as in mammals, &c.: in the cod, in which the sclerotic is chiefly made up of a cartilaginous plate, the cornea takes a fibrous origin almost altogether from the edge of the plate, and the outer surface close to the edge.

In structure the cornea is made up of layers, which can be torn off almost entire; they are blended with each other near the edge, and are fibrous, the fibres of one being at right angles to the fibres of the contiguous ones.

In the vertical section of the cornea of the cod the fibres of those lamellæ which are cut across show a fibrous structure. The fibres apparently pass vertically, and along with them a great number of strongly refracting granules of small size, some indeed very small, are seen. (Pl. VI. fig. 2.) Those layers which are cut in a longitudinal direction show some granules, but no vertical fibrillation. Between the layers of the cornea is a soft gelatinous tissue containing a few corpuscles, which swell out enormously under acetic acid.

There is no proper Descemet's membrane, that is, no structureless layer; but the innermost layer of the cornea is very fibrous longitudinally, whatever direction it is cut in, and I suppose is the analogue of that membrane.

There is much less difference between the skin and the true cornea in the conger eel than in the cod; in fact they are very like each other, except that the cornea has thicker, and not such regular lamellæ, and fewer and larger corpuscles. (Pl. VI. figs. 1 and 3.)

Sensor nerves exist pretty abundantly in the skin of the eye in the cod and eel: in the eel they are very evident and are precisely similar to the nerves of the rat: in the cod nerve-trunks ramify all over the cornea, principally made up of dark-bordered fibres, while a few single fibres may also be seen, and I believe make a plexus similar to that in the eel, superficial to the trunks; but the nerves in the cod are not easily prepared.

Are there nerves in the true cornea? In the eel there are a good number of nerves ramifying round the edge of the cornea, so the probability is that they extend into it; but I have not been able to trace them in this fish, much less in the cod. Capillaries also occur round the cornea, but sparingly; they are more abundant in the skin, but here do not go beyond the margin; they give indications of investing lymphatics, and long straight fibres are often seen passing from them far into, or even across the cornea; perhaps these are connected with the lymphatics.

Pigment-cells are very abundant round the skin, and are occasionally to be met with beneath it round the cornea; they are exceedingly beautiful in the cod, being mossy stellate cells when the pigment is expanded; in the eel they are of a rather peculiar shape, being rings of pigment.

PLATE I.

Fig. 1. Vertical section of the cornea of human fœtus of the fourth month.

Fig. 2. Vertical section of the cornea of human fœtus of the eighth month greatly swollen by acetic acid.

Fig. 3. Vertical section of adult human cornea.

Fig. 4. Vertical section of cornea of guinea-pig, showing the track of nerves simulating the "fibrous cordage" of the "anterior elastic lamina" of Bowman.

Fig. 5. Vertical section of the cornea of horse, showing numerous fine short processes passing from the corpuscles into the neighbouring tissue: also the curious wrinkling of the bundles in this animal.

Fig. 6. Sensor nerve plexus from the cornea of rat, showing nerve-cells with nuclei.

PLATE II.

Fig. 1. Sensor nerve plexus from cornea of rat, with a peculiar nerve-cell with a large oval hole in its centre, showing its probable origin from five triclonic cells coalesced.

Fig. 2. Vascular arch from the cornea of rat, showing the shrunken capillary invested with its lymphatic sheath, pigment-cells, and tissue nerves (Dr Beale's capillary nerves).

Fig. 3. Group of vessels undergoing atrophy, from the cornea of a rat in which a wound of the cornea had recently healed. Fusiform nuclei are seen edging the vessels and extending beyond their shrunken points; probably these belong to the lymphatics.

Fig. 4. General structure of a vascular arch of the cornea. *a*. The included capillary. *b*. The loose sheath formed by the lymphatic. *c*. The nuclei of this lymphatic.

Fig. 5. Portion of vascular network from the cornea of sheep, showing the capillaries surrounded by lymphatics; these are seen to contain lymph corpuscles. At *a* is seen a lymphatic without any included capillary, but with a great number of lymph corpuscles in it; these are aggregated very much at *b*, indicating very probably the place of a valve.

Fig. 6. Another capillary from the cornea of the sheep, showing its lymphatic sheath with corpuscles and a free lymphatic, *a*. At *b* this free lymphatic seems to have received a branch from the lymphatic investing the capillary, and probably one also from the left from a neighbouring arch.

PLATE III.

Fig. 1. Vertical section of the injected cornea of a kitten at the passage of the sclerotic in the cornea, showing

a. Section of the circular venous sinus of Schlemm.

b. An efferent vein passing backwards from the sinus, cut obliquely.

c. Iris.

Fig. 2. Plexus of tissue nerves from cornea of sheep.

a. End of a tuft of very small capillaries with investing lymphatics.

b. A nerve-trunk, probably containing three or four fibres, passing to supply the sensor plexus of the cornea. This trunk was considerably deeper in the cornea than the fine nerves.

Fig. 3. Group of nerve-cells from the cornea of box tortoise.

PLATE IV.

Fig. 1. Vertical section of cornea of golden eagle near the anterior surface.

Fig. 2. Vertical section of cornea of linnet, showing the manner in which the corpuscles are grouped in a layer near the anterior surface, leaving a clear space, *a*, at the immediate surface.

At *b* are seen nerves passing up to ramify in the superficial portion of the cornea.

The middle portion of the cornea is seen to contain but few corpuscles.

Fig. 3. Vascular network from the edge of the cornea of the pigeon, showing the 'investing lymphatic. At *a* is seen a loop, the top of which is out of focus, and so only the section of the capillary is to be seen.

PLATE V.

Fig. 1. A vessel teazed out of the iris of a pigeon, showing the investing lymphatic.

Figs. 2, 3, and 4. Peculiar bodies, probably nerve-cells, with a thick loose coat of areolar tissue, found connected with the nerves in the conjunctiva on the sclerotic immediately surrounding the cornea; from the human eye.

Fig. 2 has a medullated fibre which does not as usual lose its sheath before reaching the cell. Fine fibres are seen passing in three directions.

Fig. 3. A cell with no dark-bordered fibre, the trunk of fine fibres is seen loosely twisted, and one fibre separates itself immediately from the trunk, and at *a* begins to form its terminal plexus.

Fig. 4. A cell with but two fibres, one medullated and losing its sheath before entering the cell, the other a fine fibre distinctly twisted round the first.

PLATE VI.

Fig. 1. The skin of the eye in the conger eel modified to resemble the cornea. Vertical section.

Fig. 2. Vertical section of the true cornea of the cod, showing the layers of which it is composed, and large scattered nuclei lying between them.

a. a. Layers cut through longitudinally with the fibres.

b. b. Layers cut across the fibres, showing a vertical fibrillation and numerous granules.

Fig. 3. Vertical section of the true cornea of conger eel. Compare with Fig. 1.

ON HUMAN MUSCULAR VARIATIONS AND THEIR RELATION TO COMPARATIVE ANATOMY, by JOHN WOOD, F.R.C.S. *Demonstrator in Anatomy at King's College, London; Assistant Surgeon to King's College Hospital.*

THE muscular system in man, and probably also in the lower animals, is subject to irregularities producing almost every variety of anomaly. From Albinus downwards these anomalies have attracted the attention of anatomists more or less powerfully. In the earlier times, when, for want of human subjects for dissection, such animals as apes, dogs, &c. were, perhaps, more commonly the subjects of investigation than they are now, the striking similitude of many of their muscles to the human variations occasionally found, has enforced attention on the observer. Such was the case, for example, with the *Sternalis brutorum* of Sandifort and Sabatier (1790). In later years, the gradual separation of the human from the comparative anatomist, and the specialization of their respective studies, have led probably to a less distinct apprehension of the relation of the varieties in the human system to the normal muscles of lower organizations. Numerous human abnormalities have indeed been recorded by Sharpey, Quain, Hallett, Macwhinnie, and Struthers, in this country, and by Meckel, Haller, Theile, Gruber, Gantzer, Rosenmüller and Isenflamm, by Luschka, Kelch, Wagner, Fleischmann, Otto, Cruveilhier, Henle, and others, in Germany and France; but these have usually been detached observations without special reference to the coexistence of other anomalies, or to the presence of similar muscles in animals. In this respect Meckel only may be considered as an exception; and even his extensive generalizations referred rather to the normal arrangement of the muscles in man, as compared to that of other creatures, than to the varieties met with in the human subject viewed in the same way. In this department of scientific anatomy I believe that I am not alone in thinking that much remains to be done by patient and detailed investigation; and if the results at all correspond to a reasonable anticipation, much light will be thrown from this quarter upon the interesting and much discussed question of the position of man in the animal kingdom, and his relation to his inferior fellow-creatures. If, in addition to the general resemblance of the muscular mechanism, there be found in the former fragmentary records of special apparatus which have, in the latter, the fuller development of a definite purpose, then these may be taken as at least of equal importance with other evidence of

PLATE I.

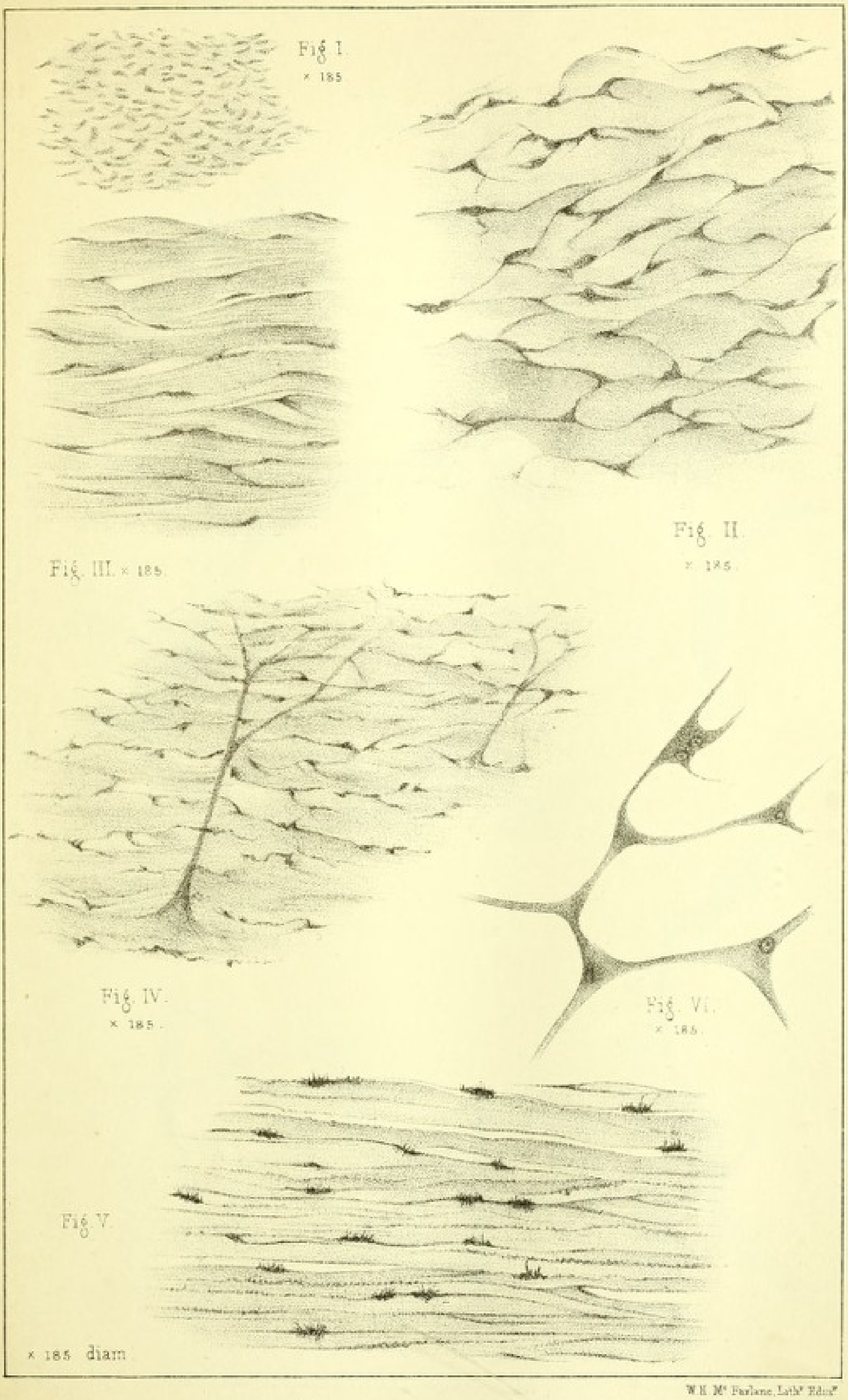

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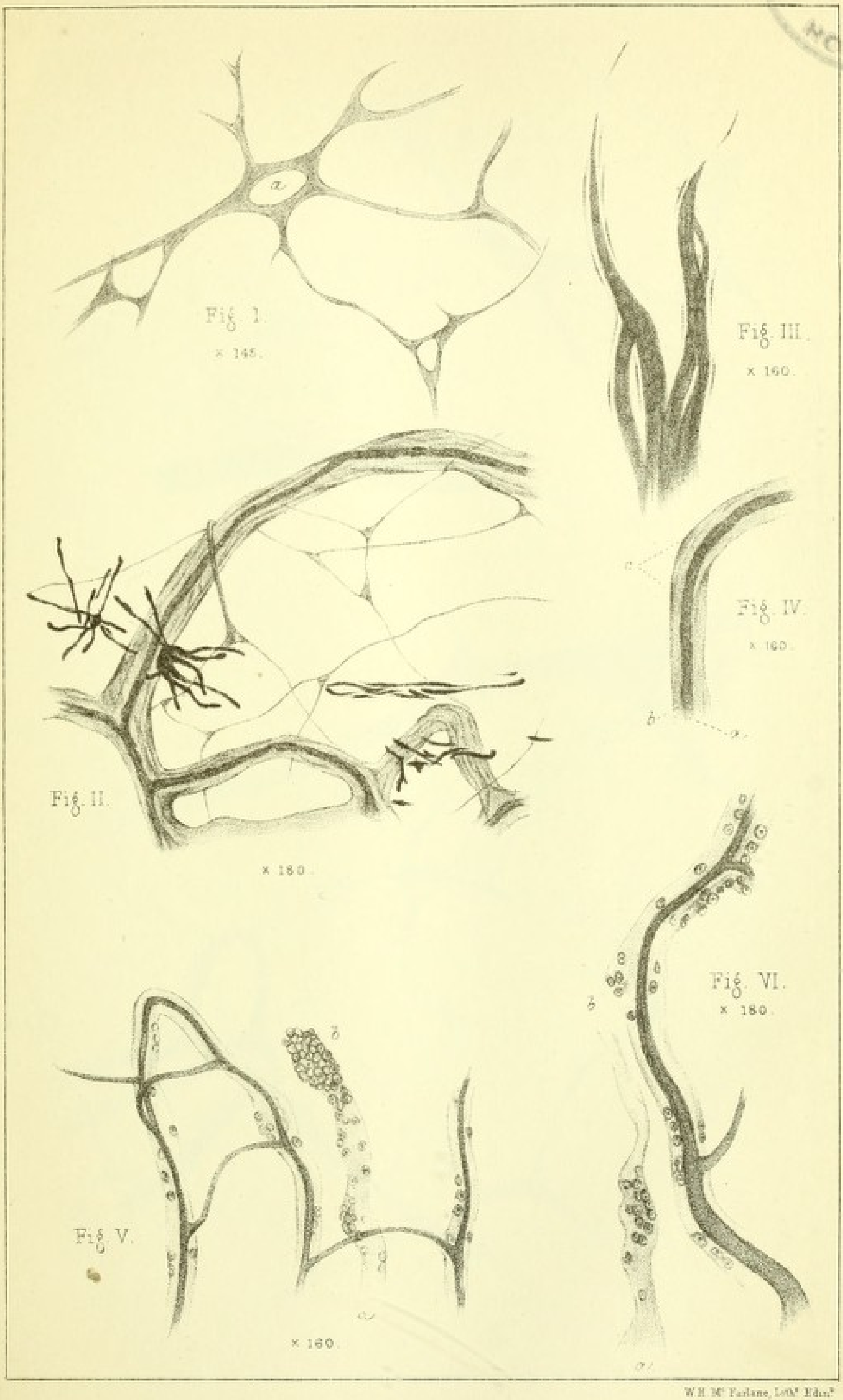
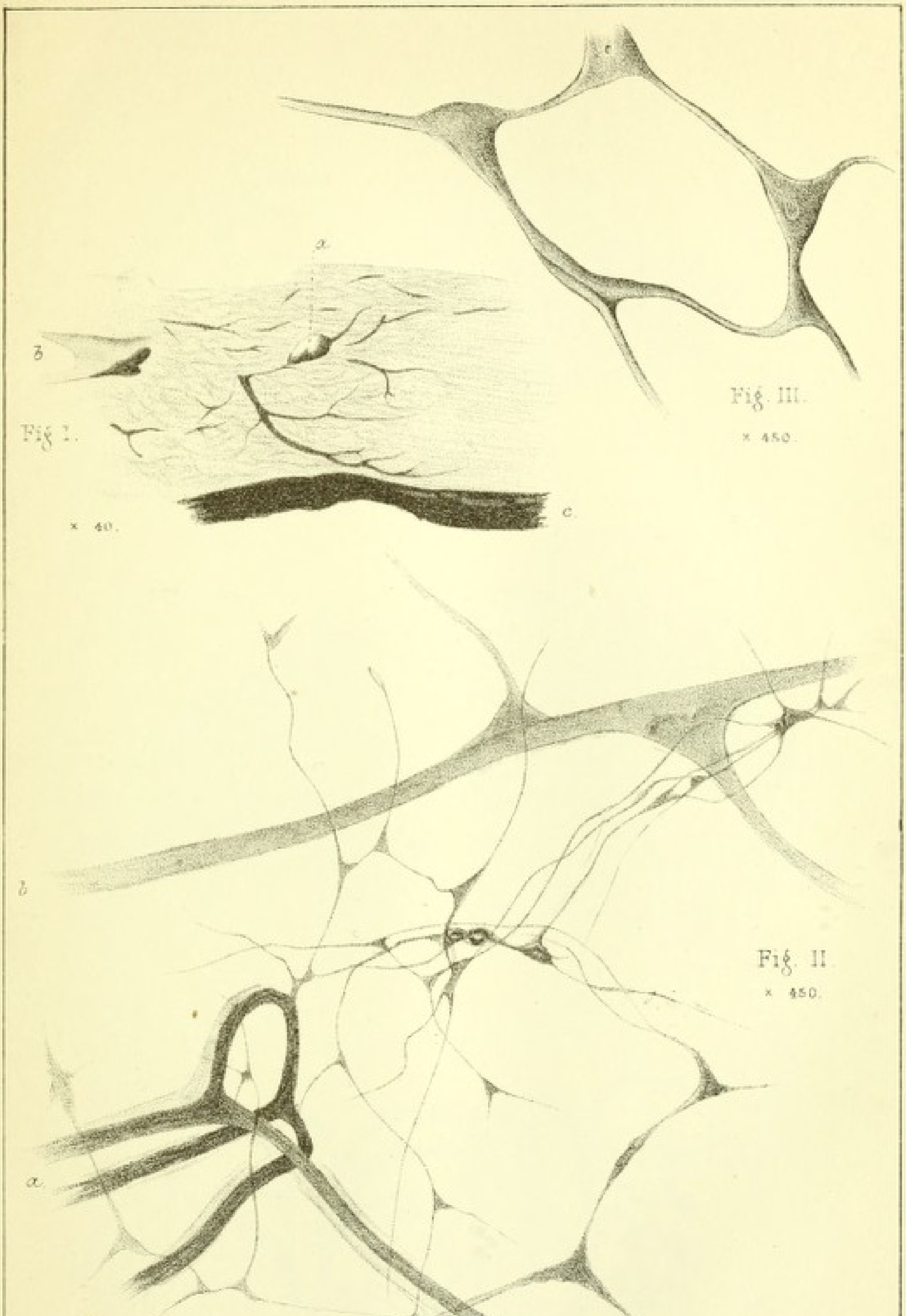
PLATE II.



W. H. Mc Farlane, Lithr Edinr



W. H. M'Farlane, Lith'r Edin'r

PLATE IV.

Fig. I.

× 180.

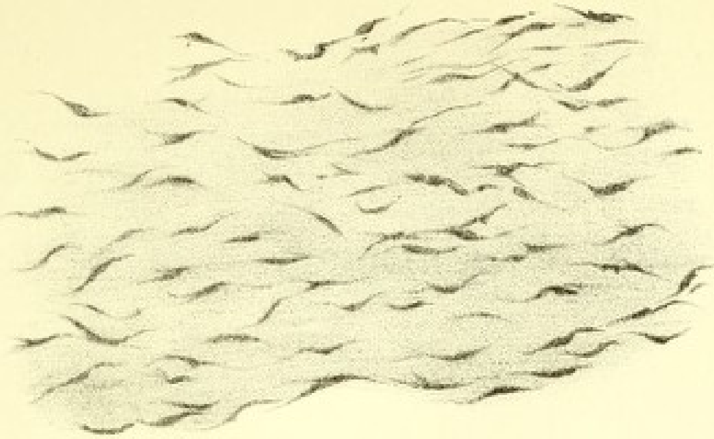


Fig. II.

× 180.

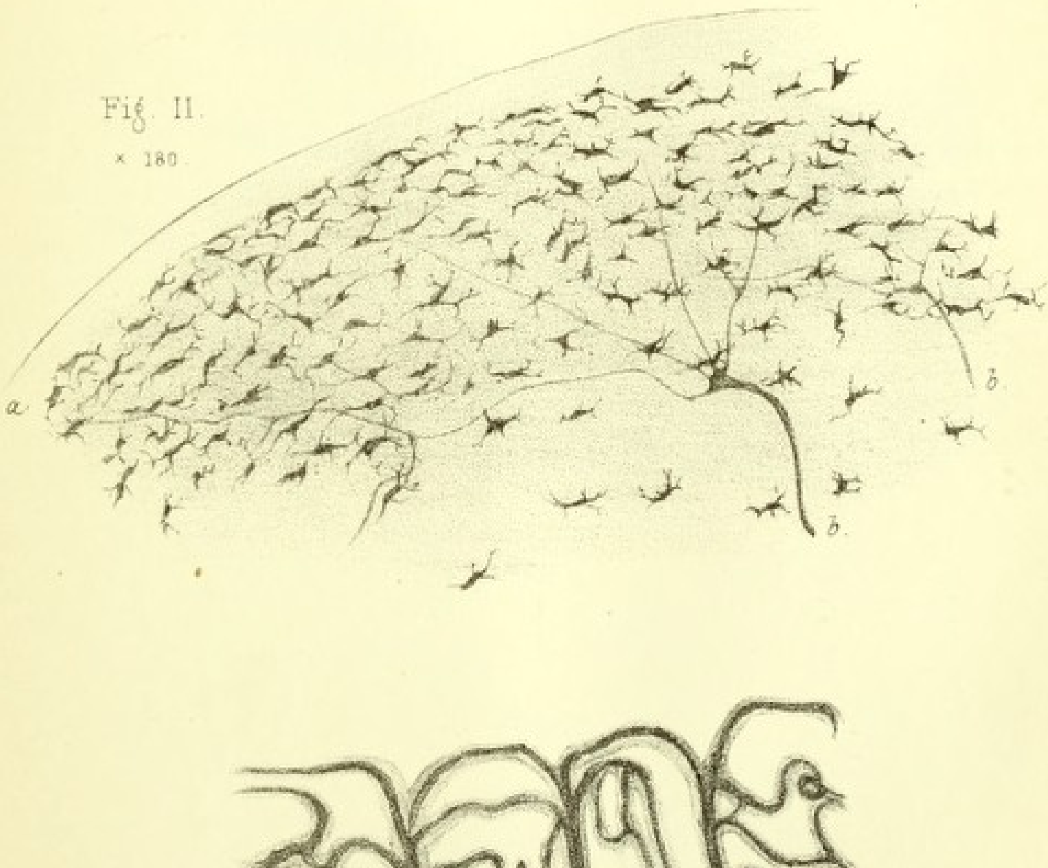


Fig. III.

× 180.

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PLATE VI.

Fig. I.

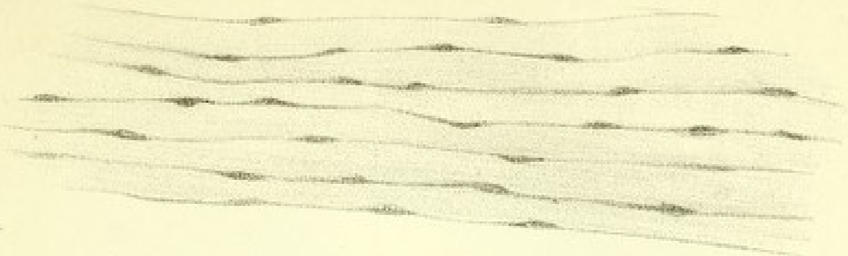

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Fig. II.

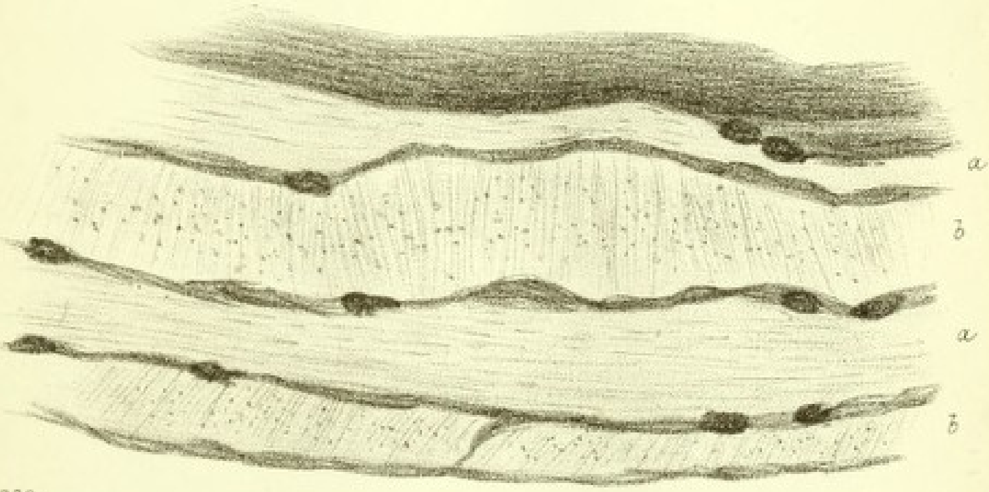

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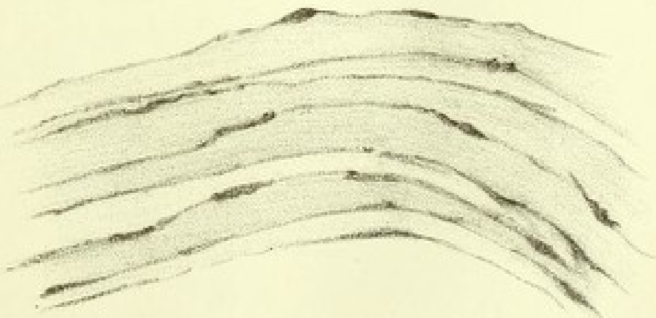
Fig. III.



× 175.

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