On the Termination of the Nerves in the Mammalian Cornea. By E. Klein, M.D., F.R.S., Lecturer on Histology at St. Bartholomew's Medical School. (With Plate XXXVII.)

There is hardly an organ in which the distribution of the fine nerves can be so easily observed as in the cornea, thanks to the invaluable discovery of Cohnheim of staining the organ with chloride of gold. Since his publication, November, 1866, "On the Termination of the Sensory Nerves in the Cornea," in Virchow's Archiv, vol. xxviii, a very great number of observations on the same subject have been published, all of which have been obtained by Cohnheim's method of chloride of gold.

On a perusal of all these publications, one arrives at the remarkable conclusion that, notwithstanding the excellence of the method, notwithstanding the distinctness with which the final nerves are traceable in all parts of the cornea, notwithstanding the great transparency and relatively simple structure of this organ, notwithstanding the absence in it of a variety of structures, such as glands, blood-vessels, &c., capable of materially interfering with the observation of the fine nerves—notwithstanding all this, there exists the greatest variety of opinion as to the termination of the fine nerves.

The arrangement of the microscopically coarse nerve branches in the cornea of the frog and mammal were understood before the use of the gold method, thanks to the researches of Saemisch, Arnold, and Hoyer; and after the gold method the observations of Cohnheim, Kölliker, Hoyer, His, Waldeyer, and others have, one might almost say, been exhaustive on the same, viz. the arrangement of the coarser branches; it is the finer and finest fibres whose termination, nay, even whose distribution and arrangement is still a matter of discussion.

The last publication on this subject is by Izquierdo, ('Beiträge zur Kenntniss der Endigung der sensiblen Nerven,' Inaugural Dissertation, Strassburg, 1879) and by Waldeyer ('Archiv f. mikrosk. Anatom.,' xvii, p. 367), chiefly relying on Izquierdo's researches carried out under his (Waldeyer's) direction. They are to the effect that the fine nerves entering the anterior epithelium of the cornea terminate in the superficial layers, in the manner described by
Kölliker and Hoyer, viz. with free ends of the same nature as maintained by Hoyer, while most of those in the substantia propria terminate in the processes of the corneal corpuscles. I shall return to these observations below in detail, but wish to point out here already that they are diametrically opposed to those that I described in this Journal in 1871 (October, 1871), and in the ‘Monthly Microscopical Journal’ (April, 1872), to the effect, first, that the fine nerves having entered the anterior epithelium and having branched and run horizontally (Kölliker) for a longer or shorter distance, terminate in a network, which I called the intraepithelial network; and secondly, that those in the substantia propria do not anastomose with the processes of the corneal corpuscles, as was mentioned by Kühne, Cohnheim, Mosely, Lipmann, and others, as will be referred to below minutely, but although in their extremely long course many times they come in close contact with the corneal corpuscles, do not terminate in them but as a network on them. For the reason of this discrepancy between my results and those of Izquierdo and Waldeyer, I have again made the nerves of the cornea a subject of investigation, and I am able to prove that neither do they terminate with free ends in the anterior epithelium, nor are they connected with the corneal corpuscles.

On making this renewed investigation, I have observed several other points which appear to me to be of importance in the discussion of the mode of termination of the fine nerve-fibres.

In order to get at the consideration of the intraepithelial fine nerves and those of the substantia propria, we shall start with the axis-cylinders, which in the front layers of the substantia propria are most numerous, forming what are called by Arnold the subepithelial, by Hoyer the subbasal, and by Waldeyer the fine stroma plexuses. We shall refer to them simply as the stroma plexus. The nature of the branches of this plexus, as bundles of primitive fibrils, the endothelial perineural sheath of the larger branches, the great difference in thickness of the different branches and in the different planes of the same branch, the angular plate-like enlargements, where two or more of them join, are so conspicuous that there are hardly any differences of opinion about them, and it is therefore unnecessary to refer to them more than in passing. There is no difference amongst the recent observers as regards the position of these plexuses. They are all agreed about their being behind Bowman’s membrane.
First, as to the relation of this stroma plexus to the sub-epithelial nerve expansion.

Cohnheim (l. c.) traced from the most anterior branches of this plexus isolated twigs, which immediately underneath the epithelium split up into bundles of elementary nerve-fibrils. Hoyer ('Archiv f. Anat. and Physiolog.,' 1866, Heft 2) already saw these twigs; and Kölliker ('Ueber d. Nerven Endigung in der Hornhaut Physic. Med. Gesellsch., in Würzburg,' 30th Juni, 1866), says of them that they pass in an oblique direction through the membrana Descemeti, in order to arrive at the posterior surface of the epithelium, and he therefore called them rami perforantes. Hoyer ('Archiv f. mikrosk. Anat.,' ix, ii Heft, p. 236) was the first who described in the most anterior layers of the substantia propria, but underneath the anterior basement membrane, a special nerve termination, the subbasilar plexus, which consists of fine and finest fibrils derived from the branches of the stroma plexus. Most of the finest fibrils after a long, straight or wavy course and after branching terminate with free ends in the tissue. All fibres of the subbasilar plexus remain underneath Bowman's membrane, and this plexus is densest in the peripheral zone of the cornea. While confirming Hoyer's observation as to the great abundance of the fine and finest fibrils in this subbasilar plexus in the cornea of the guinea-pig and rabbit, I am able to add to his description on some important points.

I will here state once for all what in the following pages I shall speak of thick and thin fibrils; as I have attempted in my former paper (1871 and 1872) so also here I distinguish the nerve branches of the stroma plexus, each of which is in fact only a bundle of fine fibrils, as nerve bundles of the first order; these give off fibres, which are to be considered as a small bunch of two or three primitive fibrils, are the nerves of the second order or the thick fibres, and the individual fibrils constituting them are the fine fibrils or the fibrils of the third order. The latter are characterised by the smaller and larger varicosities more or less closely placed.

The fibres of this plexus are of various thicknesses between that of a smaller branch of the stroma plexus and the finest fibrils marked by regular varicosities; the thicker fibrils have only a short course, since they soon branch into the finer ones. But these latter are of various types. a. Such as take at once a bold straight course, as if they attempted to run to the furthest possible regions; in this way they bend off from their course once or twice at a right angle,
but in most cases remain in the same level. b. Fibrils which take a long and wavy course, altering their direction and level many times, running repeatedly upwards or downwards in a vertical direction. In sections that are placed horizontally, and comprise the anterior layers of the cornea, these fibrils can be traced in their entire course, but it requires great attention to follow them through all their changes of level.

Now, the nerve expansion that Hoyet called the subbasilar plexus can be separated into the following three systems:—1. A plexus of thicker and finer fibrils, which lie in the same level as the most anterior branches of the stroma plexus, that is, immediately behind, and closely to Bowman's membrane. This system we call the subbasilar plexus proper. The thicker fibres of this system branch, and they and their branches run a more or less wavy course. The finest fibrils of this system pass out of this level behind or in front. 2. From the branches of the stroma plexus we trace fine fibrils, which at once pass into the layers behind, and here run for a long distance in straight lines; they branch repeatedly and anastomose by these branches in rare places with similar fibrils; they terminate apparently in the corneal substance with free ends. These fibrils constitute the deep subbasilar fibrils. We shall return to them below. As mentioned just before, some of the fine fibrils of the first system leave the level of this latter, and run behind it as straight fibrils identical with those of the second system. 3. From the level of the first system fine fibrils pass anteriorly into the basement membrane; here they may be followed in their winding course for a long distance, changing their direction repeatedly; they are not very numerous, and within this membrane may be seen to branch here and there. These fibrils may be called the intrabasilar fibrils. They and their branches have a two fold destination: a, either they again pass backwards and associate themselves to the deep subbasilar fibrils, or, as is not unfrequently the case, they pass anteriorly through the basement membrane and enter the subepithelial network to be described presently. In the Plate XXXVII, accompanying this paper, I have given an accurate representation of these different fibres in figs. 1—3.

The nerve-fibrils in the immediate proximity of the epithelium form what is known as the subepithelial network; it is made up of fine and finest varicose fibrils, and they are derived from two sources:—(a) from the rami perforantes; this source
was already known to Cohnheim, Kölliker, and Hoyer; as
Cohnheim very beautifully showed, they come off from the
rami perforantes in "bundles," except in a small central
zone. But I would add here that there exist 'bundles' also
in the central zone, but they are not so conspicuous, because
smaller. All fibrils are possessed of varicosities, and those
of the same bundle diverge the further away from their
ramus perforans; they form triangular groups, the apex of
which is directed towards the periphery.

(b) A few fibrils are derived from the intrabasilar fibres,
as mentioned above.

As regards the course of the fibrils of the subepithelial
network, they all have a linear, but more or less winding
course. Their number is everywhere very great, but there
exist remarkable differences in this respect in different
specimens. Both rabbits' and guinea-pigs' corneas, prepared
with the chloride of gold, with or without subsequent re-
duction by formic acid, tartaric acid, warmth, &c., show
some striking variations. The best results, i.e. the greatest
number of these subepithelial fibrils, I have noticed in
cornea prepared after chloride of gold, with tartaric acid
(see my paper in this Journal, October, 1871, p. 408), or
with glycerine (in the 'Monthly Micr. Journal,' April,
1872, p. 157).

In successful specimens so obtained the number of
fibrils is here astounding; it is so great and dense that we
can truly speak of a special nervous layer formed here by
fine fibrils. Such specimens are not common; they are, in
fact, rare; perhaps only one out of ten will show them to
perfection; but, since we cannot assume that this one would
in reality differ from the others, we must necessarily con-
clude that this is due to a lucky unknown condition in the
method of preparation, and I would again insist on this, as
I have done in my former papers, viz. that the description
of the distribution of the fine nerve-fibrils is probably the
correct one, which refers to the most perfect preparations.

In the specimens that we are now having before us, and
of which figs. 7 and 8 give a faithful representation of the
nerve-fibrils of the subepithelial network, it will be seen
that the individual fibrils are of very great length, but there
are differences in this respect. In fig 8 I have drawn, very
accurately, a great number of the fibrils (by no means all) of
the subepithelial network of a portion of the cornea, amount-
ing in length to about 0.4 mm., and it will be found that
some fibrils exceed this length, while others fall far short
of it.
Two facts are very conspicuous in this figure, viz. first, that most of the fibrils branch and really anastomose with another, and secondly, that, without exception, they leave the subepithelial network sooner or later, according to their smaller or greater length. With regard to the first of these facts, it will be noticed, from figs. 7 and 8, that not only do the fibrils of the same "bundle" anastomose with one another, but also those of neighbouring ones; that consequently the subepithelial fibrils are connected into real networks, as Cohnheim distinctly stated in his paper, and as I have also described and figured it. Hoyer (l. c., p. 232) agrees with Engelmann that the fibrils cross only, but do not anastomose, and Izquierdo (l. c., p. 26) mentions anastomoses between the fibrils of the same bundle, but is not certain whether this is the case also between the fibrils of neighbouring bundles.

The second fact above mentioned, viz. that all of the subepithelial network pass out of the level of this latter is easily ascertained in the preparation represented in fig. 8. It will be found here that many of the fibrils possess short lateral branchlets, which, soon after they are given off, curve hook-like, and enter the anterior epithelium. Some of the fibrils of the subepithelial network are possessed of a great number of these minute side branchlets (in the figure these are marked by a small cross), and when viewed from the surface (see fig. 8) they resemble a sort of fishing line, to which are fastened right and left a series of hooks; in our case the hooks are the little branchlets ascending into the epithelium. But also the extremity of the chief fibril itself ascends into the epithelium. In accordance with this a vertical section through the cornea show these fibrils of the subepithelial network, creeping along the lower surface of the epithelium, and giving off short branchlets, vertically ascending into the epithelium, between the cells of its deepest layer. I do not find in the description given by Hoyer, Cohnheim, Kölliker, Engelmann, Izquierdo, and others, that these minute side branchlets, as marked by a small cross in fig. 8, have been known to them in the form as they are represented in this figure. Kölliker and Hoyer have pointed out that the intraepithelial network is situated immediately underneath the epithelium, between it and the basement membrane; Krause and Izquierdo, however, think that its fibrils are sunk in between the extremities of the deepest epithelial cells. I cannot admit this latter view, since I possess preparations in which the whole epithelium, inclusive of the deepest layer, is clearly removed without
disturbing the subepithelial network, which is left untouched. Cohnheim (l. c., p. 41) mentions this already of the cornea which has been macerated in acetic acid after chloride of gold, and I can fully confirm him herein. This could not possibly be the case if the subepithelial network were not situated underneath the deepest layer of the epithelial cells. From vertical sections of the rabbit's cornea we obtain the conviction that the greatest number of these fibrils are situated above (i.e. anterior to) Bowman's membrane. Cohnheim does not admit for the rabbit's cornea a structure comparable to the similar membrane in the human cornea; there can be no doubt about its presence, and in gold specimens it is occasionally well marked as a conspicuous layer of the thickness of a lamella of the ground substance, from which it differs by its being differently coloured, but it is of the same tint as the membrana Descemeti.

Having passed into the epithelium, the nerve-fibrils ascend in a vertical manner, winding their way between the columnar cells of the deepest layer, as was first seen by Hoyer, and afterwards, by means of his chloride of gold method, minutely traced by Cohnheim. As regards the fate of these intraepithelial fibrils there is even less agreement than of that of the subepithelial ones. With the exception of Inzani, Thanhofer, and Dittevensen, all observers agree that the intraepithelial fibrils extend to near the surface of the epithelium. According to Cohnheim ('Virchow's Archiv,' Band 38), having arrived in the superficial layers, some of them branch, others not, and then they change their vertical course into a horizontal one. Some of them terminate with a minute end knob freely floating in the precorneal fluid. Kölliker followed the last termination of the intraepithelial fibrils as horizontal fibrils situated between the most superficial layer of the flattened epithelial cell. Here they run for a longer or shorter distance, branch repeatedly, and Anastomose but rarely, and finally each fibril terminates with an end-knob underneath the most superficial layer of the epithelial scales. Engelmann ('Die Hornhaut,' Leipzig, 1867), whose obser

vations refer only to the cornea of the frog, saw only free ends of the intraepithelial fibrils between the epithelial cells of the most superficial layers. At a similar conclusion arrived also Tolotschinow (Inaugural dissertation (St. Petersburg, 1867). According to Petermoller the intraepithelial fibres form networks in all layers of the epithelium. In my paper on this subject in this Journal I have described them as giving of lateral branchlets, and as forming a deep and
a superficial intraepithelial network, the former situated in the layer next to the deepest columnar cells, the latter below the most superficial layer. The fibrils of the latter branch repeatedly, and run a horizontal course sometimes for considerable distances; they join, cross each other, and wind their way between the epithelial cells, changing their level several times. I have also stated that the end-knobs that one meets with on some of these fibrils cannot really possess this character, since they are absent in others; and, besides, they are identical with those larger varicosities that occur in the course of most of the fibrils.

Hoyer ('Archiv f. mikr. Anat.,' Band ix, p. 234) describes the intraepithelial fibrils in the same way as I had done, but, while admitting anastomoses of these fibrils, maintains that they terminate with free ends amongst the superficial layers of the epithelial cells. The small and large varicosities which these fibrils show in some specimens are absent in others, and, therefore, must be regarded as produced artificially. Rollett ('Stricker's Handbook,' article "Cornea," p. 1136) does not see any anastomosis amongst the intraepithelial fibrils, but says, that having branched they terminate in free ends, often with a slight enlargement amongst the superficial epithelial layers. Waldeyer (Graefe and Saemisch, 'Augenheilkunde,' p. 210), on the other hand, maintains a terminal network of the intraepithelial nerves. Krause ('Allg. und Mikr. Anatomie,' 1876, p. 539) saw the intraepithelial nerve fibrils forming plexuses near the surface; they terminate with small end-knobs. Izquierdo (l. c., p. 27) finds that the intraepithelial nerves, having ascended in a vertical or oblique direction into the superficial layer, bend off into a horizontal course and branch. They do not anastomose. All fibrils terminate with free ends, or with a slight swelling.

Waldeyer ('Archiv f. mikrosk. Anatom,' Band xvii, p. 379), while accepting Izquierdo's conclusions, admits the incorrectness of his former view of an intraepithelial terminal network. When speaking of a terminal network (Graefe and Saemisch, p. 270), Waldeyer then observed also free ends, but "the possibility always remains that in such apparently free ends there is only an imperfect action of the chloride of gold." This is just what I have urged in my first paper in this Journal, 1871, knowing well the great differences in the number of the intraepithelial nerve-fibrils that one meets in various specimens, and in various places of the same specimen, prepared after the same plan, and seeing that in
many cases the nerve-fibril can be traced beyond an apparent end-knob.

In his last paper ('Archiv f. mikr. Anat.,' xvii), however, Waldeyer thinks (p. 329) that the reason for his formerly maintaining an intraepithelial terminal network lies perhaps in the fact that he had chiefly to deal with the human cornea, in which the cement substance becomes readily stained with the chloride of gold, and hence the appearance of anastomosis is easily accounted for. In the preparations that were the basis of my memoir in 1871, and in those of the present occasion, the intraepithelial nerves are the only fibres stained black with the chloride of gold. The epithelial cells and their interstitial substance is unstained, except a faint greyish tint in the deepest layer. The nuclei of the superficial epithelial cells are just visible, being faintly stained violet. I must repeat that in my descriptions of the intraepithelial nerves I always had to deal with such specimens only. Those in which also the interstitial substance of the cells in the superficial layers are distinctly stained have always been discarded as unsuitable, since a confusion of the interstitial cement substance with fine nerve-fibrils is then quite possible. This has been ably urged by Cohnhein (l. c., p. 31), and in the drawings of the intraepithelial nerve-fibrils accompanying his memoir (figs. 7 and 8, plate xii); in the figures given by myself in this Journal October, 1871, figs. 2, 3, and 4, Plate XIX; and in 'Monthly Micro. Journal,' April, 1872, figs. 5 and 6, plate xiv; in those represented by Hoyer ('Archiv f. mikr. Anat.,' ix, fig. 2, plate xiii,) the unmistakable and conspicuous nature and course of these fibrils can at once be recognised. To all those who have seen good specimens of the intraepithelial nerves it must be evident that, judging from the representation given in Rollett's fig. 390, l. c., p. 1136, and in Waldeyer's fig. 21, l. c., p. 210, both these authors had not seen the intraepithelial horizontal nerve-fibrils of the superficial layers, and consequently were not in a position to judge of their final distribution.

Following, then, carefully in a horizontal section—the anterior free surface being directed upwards and a place being selected that comprises only the epithelium—of a well-stained and well-reduced gold cornea, the intraepithelial nerve-fibrils, after they have passed between the columnar cells, can be traced as more or less horizontal fibrils in all layers anterior to the deepest columnar cells. The length of these fibrils varies very greatly; some of them are very short, not longer than the breadth of two or three epithelial cells, while many others may
be traced for a very considerable distance, even through several fields of the microscope. On their way they give off right and left similar horizontal fibrils; every one of them, if long enough, can be seen to change repeatedly its level, now ascending to almost the free surface, then, again, dipping down and pursuing its course among the middle layers of the epithelium. In this manner they form a very intricate texture, such as I have figured in my former papers, and as is also figured by Hoyer in his fig. 2, plate xiii. We find these fibrils in all layers, between the most superficial layer of scales and the deepest layer of columnar cells, and I must, therefore, correct accordingly my former statement as to the presence of these fibrils only in two layers (a deep and superficial intra-epithelial network), although I must adhere to my former statement that they are most numerous in the superficial layers. The fibrils are of various thicknesses; some are conspicuously thicker than those of the subepithelial network. This is especially the case with those in the superficial layers, as I must persist in maintaining against Hoyer (l. c., p. 234); but in all layers in which they occur we find fibrils of comparatively great thickness crossing and anastomosing or giving off respectively fibrils of such fineness that it is just possible to trace them. Whether very fine or not, they almost invariably possess minute varicosities, some fewer, others more; especially the very fine ones show them better and more regularly disposed than the thick. Besides these fine varicosities there are other larger ones more irregularly distributed. They are either staff-shaped, or spherical, or pear-shaped, or angular. Any of these large varicosities may be met with in the course of the fibrils where they join others or where they give off one or two lateral branches, or they occur at the apparent extremity of a fibril. I say purposely "apparently," since we shall presently see that they are not the real ends. Such apparent ends occur on the fibrils or their branches in all layers, as Cohnheim very correctly described (l. c., p. 28), except, of course, the deepest layer of columnar cells, and the most superficial one of flattened scales.

The nerve-fibrils do not pass into this last-named layer, and certainly do not extend beyond it. I have expressed myself in the same sense already in my former communications, in accordance with Köllicher. Hoyer and Izquierdo did not see them pass into the most superficial layer of scales. When looking at a horizontal section comprising the complete epithelium, it will at first appear as if some of the most superficial intraepithelial fibrils did really extend as far as the free surface. To determine this it is necessary to use high powers, such as Zeiss's $\frac{1}{2}$ oil immersion, or Hartnack's 10 immersion; it will then be seen that one layer of nuclei (i.e. those of
the most superficial scales) can be traced above the most superficial nerve-fibrils. On account of the great thinness of the superficial scales even a moderately high power, such as Zeiss's D and E (\(\frac{3}{4}\) and \(\frac{1}{4}\) inch), or Hart-nack's 7 and 8, does not suffice. Amongst the great many specimens which I have examined—they amount to hundreds—only in very rare instances have I seen one or the other fibril at the same level as the most superficial nuclei.

Before coming to their ends I must say a few words as regards their relation to one another. Cohnheim (l. c., pp. 27 and 28) does not speak of any anastomosis of the intraepithelial nerve-fibres, while Kölliker (l. c., p. 4) observed such anastomoses, "although, as it appears, not frequently." Anastomoses of the intraepithelial nerve-fibres, although, on the whole, rarer than I thought them to be in my first memoir, do no doubt occur. My mistake of assuming them to be of very frequent occurrence arose from my not having examined with sufficiently high powers.

It must be borne in mind that these fibrils in many places, when crossing, are in very close contact, and if they happen to cross at the point of a varicosity the appearance of an anastomosis is produced. When examining such places with an oil immersion \(\frac{1}{2}\) of Zeiss I can ascertain that in four out of six there is really no anastomosis between the fibrils; in the other two it is impossible to say that there is not an anastomosis. But there exist real anastomoses, about which there can be no doubt whatever; these refer to such places where two of the long fibrils are joined with one another by a shorter or longer side branch. In fig. 10 are represented such undoubted anastomoses.

Now, as to the larger or smaller knob-like structures which are met with on the apparent extremities of the shorter as well as the longer fibrils, as mentioned above, and as observed by all who have worked at this subject, there is no doubt about their presence, and the question is whether they are the real ends or not. Kölliker (l. c., p. 4) would not say that these knobs are natural or artificial, Hoyer (l. c., 234) considers them as artificial products, and Izquierdo (l. c., p. 28) asserts that some fibrils, at any rate, possess them. Cohnheim, Tolotschinow, Krause, and others, consider them as natural end-knobs.

It cannot be denied that they possess the same appearance, whether at the end of a fibril or in its course; but the great differences in their number, size, distribution, and shape, seems to point to their being artificial products. That some of them are not "end-knobs" this I am going to prove presently; that others are such is doubtful, since it cannot with any show of reason be asserted, as Izquierdo does, and
as Waldeyer confirms, that there exist two modes of termination—one with end-knobs, and the other without.

What is, then, their real termination?

In preparations which would pass the muster of good nerve preparations, there is nothing to be seen, even when examined with a high power, beyond the fibrils as figured by Cohnheim, myself, Hoyer, and Izquierdo, and as now represented in the figures of the Plate accompanying this present memoir. But after they have been kept mounted in glycerine for some time—I refer here to specimens of the rabbit's cornea prepared after the simple (Cohnheim's) method of chloride of gold, as well as that where afterwards a reduction is effected by means of tartaric acid (see my former paper in this Journal) and mounted in glycerine for one or two years—and if they are then carefully examined, it will be found that in some of them a great many exceedingly fine fibrils are seen, which are given off by the above ordinary intra-epithelial fibrils, both as lateral branchlets and from the knobs that previously appeared as end-knobs. These fibrils, which at the time the preparation was mounted could not be seen, are now distinctly traceable, some for a long, others only for a short distance. In some places they appear as a row of minute stained dots with unstained joints between, while in others both the dots and joints are stained and then easily perceived. Following under a high power, e.g. Zeiss' oil immersion, which by its exquisitely fine definition is admirably suited for this purpose, one of the fibrils in the superficial layers—of course, only thin horizontal sections of the epithelium being referred to here—we are at once struck by the very great number of short lateral rod-like projections which are seen on most fibrils, both the ordinary ones as well as the very fine ones just mentioned. Generally, but not by any means always, they are given off at the varicosities. Especially interesting are, in this respect, the knobs which were above referred to as end-knobs; some of these appear beset with these projections on their whole circumference, and resemble, then, somewhat the thick extremity of a stamen with its radicles. Most of them are very short, rod-like, others can be traced for long distances, and in this case they are invariably dotted, and present themselves as regularly varicose fibrils, giving off likewise numerous lateral branchlets. Also in this case, either only the varicosities appear stained and the joints unstained, or the joints are faintly stained. Now, both the short rod-like as well as the longer filamentous branchlets, ramifying dendritically and uniting by their branchlets,
break up into a network, which is of exceeding minuteness. The network appears composed of small rods of equal length, and at all the nodal points there is a minute dot or granule. These rods appear generally faintly stained as compared with the dots, but in some places they are stained as much as the latter. Only in few places have I seen this network very perfect, and then only over a small space, but then it appeared with sufficiently great distinctness as a reticulated plate-like expansion of some of the fine nerve-fibrils. This minute network, which I shall call the terminal network, is shown in figs. 11, 14, 15, 16, and I must refer the reader to these figures which give a more comprehensive idea of its nature than any lengthy description; it is situated between the epithelial cells, since we see it from its broad surface and in profile (see figs. 11 and 16). As mentioned on a previous page, fibrils with end-knobs are met with in almost all layers, and so, I presume, is also the terminal network, but for obvious reasons it is only distinctly traceable in the superficial layer.

In the above figures I have, for the sake of comparison, added a few nuclei of the flattened epithelial cells; these nuclei are just visible as faintly outlined oval or spherical discs, of a pale grey or bluish colour; of the outlines of the cells themselves nothing can be seen.

Thus, it is easily recognised that the nerve-fibrils we have to deal with here as connected with the end reticulum are considerably finer than those drawn by Hoyer (fig. 2, pl. xiii), or Izquierdo (l.c., fig. 5, pl. i). The fineness of the terminal network is by no means inferior to that of the terminal network which I described of the nerves in the skin of the tadpole, and situated immediately underneath the epithelium ('Sitzungsber. d. k. Akadem. der Wiss.,' Vienna, 1870, vol. 61), and also observed by Lavdowsky ('Arch. f. norm. und path. Histolog.,' 1870, and 'Centralblatt f. med. Wiss.,' 1872, No. 17), nor that discovered by Gerlach in the grey matter of the spinal cord ('Centralblatt f. d. medizin. Wiss.,' 1867, Nos. 24 and 25), and by Rindfleisch ('Archiv f. mikr. Anat.,' viii, p. 453) and Gerlach ('Centralbl. f. d. medizin. Wiss.,' 1872, No. 18), in the grey matter of the cortex of the cerebrum. If Waldeyer in his last article ('Archiv f. mikr. Anatomie,' xvii Band, iii Heft) sums up by saying (p. 379) that there exist no terminal networks, and that the fine nerve-fibres ending in the epithelium, either run out freely or end with a minute knob, it is necessary to remind the reader that Waldeyer bases himself on Izquierdo's specimens, which, as far as refers to the intraepithelial nerve-
fibrils, I consider imperfect, and Waldeyer's assertion must therefore be taken to have the value of negative evidence only. That the reduction of the gold in Izquierdo's specimens has not been complete is further proved by his saying (l. c., p. 29) that, "in vain have we searched in the epithelium for the cells of Langerhans, which Ribbert pretends to have recently found." These cells—elongated cells with very many finer and thicker branched processes—it is true, are not met with in ordinary specimens, but in those in which the reduction of the gold has been complete they are very conspicuous by their colouration and size. Their number generally varies in the middle and superficial layers of the epithelium in different places and their processes, although crossed by the intraepithelial nerve-fibrils, appear nowhere connected with them.

The assertions of Inzani (quoted by Izquierdo, l. c., p. 16) about special terminal ends situated amongst epithelial cells of the deepest layer and possessed of minute fibrils, as well as those of v. Thanhoffer ('Virchow's Archiv,' Band 63, 1875) about the fine nerve-fibres terminating in so-called tactile corpuscles, situated between the cells of the deepest layer of the epithelium, are obviously due to imperfect specimens. This is well illustrated by the fact that Thanhoffer did not see any nerve-fibrils beyond the deepest layer of cells. To a similar cause, viz. to imperfect specimens, must be also attributed the assertions of Beale about the absence of nerves in the epithelium. Beale did not see any nerve-fibres in the anterior epithelium of the cornea, but then this observer did not make use of the chloride-of-gold method.

The last point which I wish to discuss here is the termination of the nerve-fibrils in the substantia propria. As is well known, Kühne was the first to maintain that in the frog's cornea the finest fibrils terminate in connection with the processes of the corneal corpuscles. The number of observers who made this a special point of investigation, although great, range themselves in those who confirm Kühne, Moseley (this Journal, July, 1871), Königstein ('Sitzungsber. d. K. Akad. in Wien.,' 1877, Band 76), Izquierdo (l. c., p. 25) and Waldeyer (l. c., p. 378); both these last-named observers assert, however, that some fine fibrils terminate also free in the substantia propria. Then those who simply deny such a connection, and accept a free ending of the fine nerve-fibrils in the substantia propria, Kölliker (l. c.), Engelmann (l. c.), Dwight ('Monthly Micr. Journal,' 1869),
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Tolotschinow (l. c.), Rollett (l. c., p. 1188)—who is, however, not able to say in what way they terminate—Hoyer, and Krause (l. c.). And, lastly, those who maintain a special termination of the fine nerve-fibrils, Lipmann ('Virchow's Archiv,' Band 78, p. 218), who says that the fine fibrils terminate in the nucleoli of the nuclei of the corneal corpuscles. Lavdowsky ('Archiv f. Mikr. Anat.,' viii) assumes two kinds of terminations of the nerve-fibrils, (a) in rhombic plates, supposed to be present in the wall (?) of the lymph-canalicul system (dog), and (b) with peculiar enlargements near the nucleus or in the nucleolus (frog, dog, cat, calf). In my former papers I have stated that the finest nerve-fibrils in the substantia propria, in good gold specimens of the frog's cornea, are conspicuous by their great length, their peculiar rectilinear course, their right-angled bending, their few branchings; these fibrils I described as the nerves of the third order, and as being nowhere in connection with the corneal corpuscles, although they come in close contact with them in many places; they are not the finest nerve-fibrils, as assumed, since in some places they are seen to give off very minute short fibrils—nerve-fibrils of the fourth order—which, on the surface of the corneal corpuscles, anastomose in a sort of network.

I have now extended my observations on the fine nerve-fibrils in the substantia propria of the cornea of the kitten and rabbit, and I must also for these maintain that the fine nerve-fibrils that one sees in ordinary gold specimens are not the finest and last fibrils. Especially easily followed are the fine nerve-fibrils in the anterior strata of the substantia propria, where they form what we considered above as the deep subbasilar fibrils, and which have been very beautifully described already by Hoyer. But also in the deeper sections of the substantia propria similar fine nerve-fibrils can be met with. Their general character is that they may be traced for very long distances; that they possess now a rectilinear, then, again, a wavy course; that they keep close to the corneal corpuscles, always running in the lymph-canalicul system, as was already known to v. Recklinghausen, and as was very extensively described by Lavdowski and Hoyer; that they give off from place to place a lateral branchlet; that in some parts they are seen to bend off suddenly at a right angle, either after a long rectilinear or curved course, or at short intervals; further it will be noticed that they continually change their level, now passing into a stratum above or below, then again returning into their original plane; and,
finally, that they anastomose, in a few instances, with their neighbours.

These fibrils differ in thickness, and they all contain small or large varicosities, more or less regularly disposed. I must draw the attention of the reader to figs. 4 and 4A, and 5, in which the nature and course of these fibres is drawn very accurately. In what way do they terminate? As is well shown in the figures, after having given off one or more branches, they, as well as their branches, appear to terminate freely either at a varicosity or beyond it, at the side of a corneal corpuscle. In this respect I can add little to the description given by Hoyer of these fibrils with admirable faithfulness.

In the cornea of the frog these fibrils are much more difficult to trace, since their great number is compressed into the posterior strata of the substantia propria, that is, into a very limited space. For this reason we find that anastomoses between neighbouring fibrils are more common than in the cornea of the rabbit and kitten.

I possess specimens both of the cornea of the rabbit and kitten, and also of that of the frog, wherein I find places in which these fibrils, when examined with a high power (Zeiss' F, or, still better, oil immersion 1/10 th), give off very minute short fibrils, which close to the surface of the body of the corneal corpuscles give off short, exceedingly fine, dotted fibrils, which themselves are connected into a network. It is, of course, easily understood, that in many instances it is impossible to distinguish between dots that are contained in the substance of the corneal corpuscles and the dots that mark these terminal fibrils; but in certain other instances this distinction is possible, viz. in those instances in which the corneal corpuscles and their processes are stained only a greyish tint, while the nerve-fibrils and their varicosities, owing to the complete reduction of the gold salt, possess an almost black colour.

In some specimens, however, we find also nerve-fibrils in connection with the processes of a corneal corpuscle, such as is described by Moseley, Königstein, and Izquierdo, and there seems no mistake about the nerve-fibrils being here directly continuous with a corneal corpuscle. But let us for a moment inquire, What are these specimens? As is known to everybody who has examined a number of corneae, either prepared after the simple (Cohnheim) method of chloride of gold, or, in addition to this, after using various reducing agencies, such as oxalic acid, formic acid, methylated spirit, or simple heat, hardly a single cornea is obtained in which the substantia propria appears throughout of the same tint. In
some corneæ in a greater or smaller portion, the corneal corpuscles and their processes are of a deep reddish-purple or reddish-black colour, while in others the corneal corpuscles are hardly at all stained, or only of a light grey or bluish-grey colour. The same difference may occur in one and the same cornea, and, of course, we then find zones of transition of the former into the latter. Let us take a cornea in which the corneal corpuscles and their processes are conspicuously brought out, and well and deeply stained, and let us add that in the majority of these instances also the fine nerves are well stained, i.e. of the same deep colour as the corpuscles and their processes. And let us bear in mind that the nerve-fibres are situated in the lymph-kanalicular system which also contains the corneal corpuscles and their processes. Let us further bear in mind that these nerve-fibrils and their branchlets run out close to the corpuscles and their processes. Under these circumstances nobody will, I think, be in a difficulty to explain the above-mentioned connection of the nerve-fibrils with the corneal corpuscles. Supposing in the preparations represented in fig. 4, 4A, 5, and 6, the corneal corpuscles were as deeply stained and of the same colour as the nerve-fibrils, nobody could fail to find here connections between the former and the latter; and, indeed, in the very same specimens from which these drawings were made there are places in which, owing to the deep colouration of the corneal corpuscles and their processes, the distinction between them and the fine nerve-fibres is lost, and, therefore, an apparent connection between them is found to exist. It is quite clear that such places are useless for determining the relation between the nerve-fibrils and the corneal corpuscles, and it is to me inexplicable how Izquierdo omitted to bear this in mind, since Hoyer (1. c., p. 241) had already drawn attention to the great importance of having specimens in which the corneal corpuscles and nerve-fibrils are of a different colouration. Izquierdo's drawings (plate i, figs. 1, 2, 3, and 4), leave no doubt that he had to deal with specimens in which the corneal corpuscles and their processes and the nerve-fibrils were very deeply and uniformly stained. For this reason, then, his assertion about the direct connection of the processes of the corneal corpuscles with the fine nerve-fibrils, and consequently also Waldeyer's summing up (l. c., p. 378) based upon it, loses the value attributed to it.