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THE

CEREBELLAR CORTEX.

BY

C. E. BEEVOR, M.D., Lond., M.R.C.P.,

ASSISTANT PHYSICIAN TO THE NATIONAL HOSPITAL FOR PARALYSED AND EPILEPTIC, LONDON.

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THE CEREBELLAR CORTEX.[1]

BY C. E. BEEVOR, M.D. LOND., M.R.C.P.

Assistant Physician to the National Hospital for Paralysed and Epileptic, London.

Dr. Gaule, under whom I have worked, and whom I have much to thank for his kind assistance, advised me to use Weigert's säure fuchsin method (*Centrbl. für die med. Wiss.* 1882, p. 753), which has produced excellent results. The first sections were made from pieces of cerebellum, one centim. square, hardened in three per cent. solution of bichromate of potash and kept in a hot chamber at 35° C. for 4–8 days. They were then washed in water half an hour, then placed in alcohol 24 hours, and then for 24–28 hours in a concentrated aqueous solution of säure fuchsin, also at a temperature of 35° C. The pieces were then slightly washed in water and put into strong alcohol and dehydrated, imbedded in paraffin and cut into sections, which were then fixed to object slides, the paraffin dissolved out,[2] and the sections washed out according to Weigert's method with water and alkaline alcohol.

In the second series of preparations they were further stained with nigrosine after the above treatment; and these preparations proved the best. The third series were hardened in the same way, but after fixing the sections on the slides, they were stained by hæmatoxylin and eocene. This latter method of double staining has already been employed by Denissenko. In the fourth method employed, the pieces of cerebellum were hardened by $\frac{1}{4}$ % chromic acid, imbedded unstained, and the sections fixed on the object slide. The specimens were taken from the cerebellum of man (adult and new-born) dog, rat, rabbit, hen and pigeon. My description is chiefly concerned with the dog, in which all the elements are most clearly shown. The human cerebellar cortex is the most developed, and as it is much richer in medullated fibres, and the medullated sheaths are better developed, it would undoubtedly give better preparations, but unfortunately it is impossible to harden the pieces directly after death and so obviate post-mortem changes. And great stress is laid on the fact that in the preparations used for this paper, in less than an hour after death, the pieces were in the hardening fluid in the warm chamber, which was used to introduce a quicker diffusion in the substance of the piece.

[1] This article is an extract from a paper published in the 'Archiv für Anatomie und Physiologie' (Physiologische Abtheilung) and from work done in Professor Ludwig's Physiological Institute in Leipzig.

[2] Canini, in these Archive, 1883, p. 155.

1.—Granule Layer.

Basis of description, säure fuchsin and nigrosine preparations. In these the medullated fibres are seen, as described in Fig. 1 and 2 *a*, as a black or grey thread enclosed in the medullary sheath stained red. It is very important to note that the axis cylinder is dark and the medullated sheath red. If the säure fuchsin be not sufficiently washed out, other fibres which are not medullated are dyed red, but these have not the dark, central fibre which can be stained by nigrosine or hæmatoxylin, and my description refers only to these fibres.

Fig. 1 is a longitudinal section of a lobule of the cerebellar cortex seen under a low power. Along the centre of this run the medullated fibres, radiating out and passing through the granule layer in the direction of the Purkinje cells. These fibres have been described by Deiters,[1] who maintained the connection of the axis cylinder process of these cells with a medullated fibre. Koschewnikoff[2] has isolated Purkinje's cells in connection with a medullated fibre. Hadlich[3] says that from the white medullated-fibre centre, fibres proceed to the grey red granule layer, divide, and pass as a principal nerve process into the large ganglion cell, into every cell one fibre. Golgi[4] makes the axis cylinder process, in its course through the granule layer, give off branches at right angles. Other descriptions are of a similar nature. But how very indistinctly the fibres have been seen is shown by the very contradictory statements, as for instance some say: that the axis-cylinder runs direct to the medullary centre; that it runs in a horizontal direction; that this axis-cylinder soon gets a medullated sheath, or that this occurs at a great distance from the cell; and that the fibre is fine,—or thick. Nearly all maintain that it divides. Hadlich, and, later, Denissenko make reservations on account of possible deceptions. Hadlich's statements seem to me the most correct.

Fig. 1 shows a clear picture of the whole arrangement of the nerve-fibres; in each lobule some of them can be traced uninterruptedly in their whole course to the immediate vicinity of the Purkinje cells. The fibres leave the medullary centre with the slightest change of direction. At the summit of the lobule they radiate out like the outstretched fingers of the hand. At the lateral part of the lobule they ascend slantingly in a slight curve through the granule layer. They run at definite distances from each other, corresponding to the distances between the Purkinje cells, to which their number, as far as can be ascertained, corresponds. At the bottom of the sulci the fibres are closely aggregated and several pass through the granule layer together.

[1] Deiters, 'Untersuchungen über Gehirn und Rückenmark.' Herausgegebene v. M. Schultze. 1868.

[2] Koschewnikoff, "Axencylinderfortsatz der Nervenzellen im Kleinhirn des Kalbes;" M. Schultze's 'Archiv,' 1869, Bd. v.

[3] Hadlich, "Mittheilung über den Bau der menschlichen Kleinhirnrinde." Arch. für mikr. Anat.,' 1869, Bd. vi.

[4] Golgi, 'Centralbl. für die med. Wiss.' 1879.

These fibres make a bend at the border of the molecular layer, running parallel with it for a short distance (see fig. 1); they do not cross each other and do not branch; but keeping the same thickness, they run straight through the granule layer with some slight wavings in their course. Their axis-cylinder is thick, the medullated sheath slightly varicose, often presenting a jointed appearance. In short, these fibres have in the granule layer the same formation they had in the medullary centre. Each remains an isolated medullated fibre which, unbranched and independently, directs its way towards a particular ganglion cell. One can hardly doubt that these are their nerve fibres. Sections are not very adapted to trace the passage of a fibre into a structure of so much greater size. If the sections are very thin, the chances of finding the right spot are extremely small, and this difficulty is increased as the fibres always change their direction before entering the cell. Isolated preparations show more easily the connection, but then it is not certain that the fibres are of the same nature. I have therefore not been satisfied till I could confirm also in section preparations the connection of the Purkinje cells with one of these fibres.

It can therefore now be said for certain that every Purkinje ganglion cell is in connection with a distinct, isolated, medullated nerve fibre. Besides the above described fibres, there are others, which have already been seen and which caused the different opinions concerning the fibres going to the ganglion cells, as it was not known that there were two different kinds of fibres. Only Hadlich [1] has as yet expressed this idea, and laid stress on the fact that the many divisions described must refer to fibres of the second kind. The second form of fibre produces a plexus which traverses the granule layer in all directions, passing into the medullary centre on one side, and into the molecular layer on the other. These fibres branch about and anastomose, they are of different thickness, from the finest calibre up to that of the first kind of fibres, their medullated sheath is less developed, is always varicose, often interrupted, and sometimes the fuchsine reaction entirely fails. In man these fibres appear far more numerous and better developed than in the dog, when stained by säure fuchsin. Perhaps age makes some difference.

It is quite clear that these fibres differ from those of the first kind. The latter pass through them without being connected with them. Probably all branched fibres belong to the same species and have the same function. I shall designate the direct fibres of the first kind, joining ganglion cells as *straight*, or *unbranched* fibres, those of the second kind as *branched* or *anastomosing* fibres.

The spaces between the fibres in the granule layer are filled up by the closely packed cells. Formerly these cells were all called granules, and their cellular nature was doubted. Denissenko has shown that we have here two kinds of cells, one stained by hæmatoxylin, the other by eocene. The hæmatoxylin cells correspond

[1] Hadlich, op. cit. p. 20.

to those formerly called granules, but they possess a nucleus and protoplasm, and therefore the attributes of a cell. Denissenko regards these as connective tissue cells, whereas the eocene cells are connected with nerve-fibres.[1] The reason why this formation was not recognised before, was because the cells are so tightly packed. Very thin sections have to be stained by a dye which will colour the protoplasm, for this is always present in the form of a very small layer around a relatively large nucleus. The protoplasm has numerous processes, very fine or thicker threads, which form a thick network with the threads of other cells.

The threads refract light strongly and have a sharp contour, the meshes are fine. They are best seen, where the cells lie less packed together, at the borders of the granule-layer. Towards the medullary centre there is no sharply-defined boundary, and as in the granule layer there are everywhere fibres, so in the medullary centre there are similar cells scattered everywhere. But here the protoplasm is more abundant, the threads thicker, and the meshes of the network are very much larger and join with the narrow network inside the granule layer, re-embling the fine framework in the white substance of the spinal cord. The nucleus of these cells is very large and characteristic. It possesses a distinct thread-like appearance, with the above-mentioned method of hardening. The threads lie grouped in all kinds of forms in a round clear space. If these nuclei were richer in colouring matter, and if characteristic stages could be found, the idea of nucleus-division might be entertained. Some of the nuclei are certainly larger and their contour more distinct. The mass which is coloured by hæmatoxylin is naturally that of the nucleus threads, while the protoplasm, even when coloured by nigrosine, only appears as a narrow line running round the nuclear spot. Between the cells the medullated fibres make their way, and their medullated sheath comes into most intimate contact with them. The cell threads often seem to penetrate between the separate particles of the medullated sheath. Denissenko describes these cells as grouped round openings from which channels proceed, whose walls are likewise lined by these cells. This appearance is seen when the cells lie particularly close together. These channels are only the medullated fibres which have penetrated between the cells, whilst the place where the fibres cross each other gives rise to the apparent openings. If the cells are less closely arranged, the spaces occupied by these fibres are less compressed, and this presents the appearance of cells in groups surrounded by fibres.

In these spaces other structures are seen, which colour with eocene and nigrosine, and called by Denissenko, *eocene cells*. They seem to be interposed in the course of the medullated fibres, which cross over the cells. They are often really interposed, as can be seen by using nigrosine and säure fuchsin, when the cells become the same colour as the axis cylinder which is then seen

[1] Henle and Merkel have already compared the granules to the cells of reticulated connective tissue, and have therefore described them correctly according to their appearance.

to be in connection with them, while the medullated sheath is interrupted.

Their cellular character is doubtful, as I can find no nucleus in most of them. The larger ones resemble multipolar ganglion cells by their form and size, as also by their connection with nerve fibres; and as it is often difficult to discover a nucleus in ganglion cells when the protoplasm is coloured, these are probably ganglion cells. The smaller of these cells are often deficient in any cellular character and appear to be thickenings along the axis cylinder.

I think I can with certainty explain the use of the hæmatoxylin cells, viz. that of glia-cells. These have not only nuclei, but are cells with protoplasm and processes; the processes form a network which extends through the whole granule layer, and which is also connected with a similar network in the medullary centre.

These appearances are just the criterion of glia-cells, and if one accepts glia-cells at all, they must be cells like those above described. Schwalbe has lately objected to the glia-cells generally, from the hypothesis that the cells can be separated from the fibres of the finest network. But these objections are mostly theoretical. Besides, in my preparations, the network of the fibres proceeds from the body of the cell (see plate Fig. 2, *b*) and this agrees with what Henle and Merkel give in their work on the supporting structure of the central nervous system. Also in the description of the supporting framework of the molecular layer I have only to confirm their observations, agreeing with them that these cells are glia-cells, but doubting that they are cells of reticulative connective tissue, or that they may become ganglion cells. Since the embryologists have shown that the central nervous system proceeds from the ectoderm, and that there exists a thorough separation between the epithelial and connective tissue structures, the "archiblastic and parablastic" formations, it is probable from embryological researches, and what we know of its chemical nature, that the glia is an epithelial formation.

The glia stands in relation to the ganglion cells and their protoplasmic processes, as the medullated sheath does to the axis cylinder of the peripheral fibres. It is a continuation of this latter, and there are forms of transition. The cellular elements are common to both; from this can be explained, what might be considered an objection to the definition of these granule cells as glia-cells, viz., their accumulation into distinct regular layers. Where numerous fibres lose their medullated sheath (those of the first type), or acquire it (those of the second type,) there are to be found accumulated the cellular elements which are common to the glia and the medullated sheath, and where this occurs in regular planes in the cerebellum, the position of the cells is found to correspond.

2.—Molecular Layer.

a. The ground Substance.—This layer owes its name to the peculiar substance forming its foundation. The older authors

describe it as a finely granulated mass, in which a finer structure is not recognisable; however Fromman has already shown it to be a sponge substance built out of a network of threads. Kühne and Ewald have proved that we have here a formation of a peculiar chemical structure, analogous to the horny framework of the medullated sheath of the peripheral nerves. Schwalbe describes the substance in his 'Lehrbuch der Neurologie' as a fine network, the fine trabeculæ being composed of neuro-keratine. This opinion is also borne out by my plates, Fig. 2, *b–d*. The clear substance lying in the enclosed spaces of this network becomes, with the means used to clear up the medullated substance, as clear as this latter; the osmic-acid method cannot be applied, as the distinction between the trabeculæ and its meshes only comes into view with very thin sections, and these can only be made after treatment with alcohol. The säure fuchsin method, however, produces a very characteristic action on erythrophile substances. In many of the mesh-spaces, but not in all, a fine red line bounds the clear contents, in the same way as seen in the cross-section of nerve-fibres.

These red-bounded spaces are larger or smaller in size, and sometimes several in a row. But they are not sections of fibres, as can be seen from the absence of any axis cylinder; neither are there, where they lie, so many fibres visible, which is easily proved by altering the direction of the section. It thus becomes probable that as this network corresponds to the horny framework of the medullated sheath, so also this intermediate substance corresponds to the myelin; but not chemically, for even the medulla substance of the periphery differs from that of the central nervous system in not re-acting to säure fuchsin; and we must consider that the relation of the neuroglia of the central nervous system differs more from the peripheral nerves than does the medulla of the fibres of the central nervous system. There are, however, many transitions, viz., the above described varicose sheaths of the branched fibres, which often form separate round formations and the glia-nets containing erythrophile substance. Another analogy becomes visible, when we consider the cellular elements of both, viz., the glia and the medullated sheath. Ranvier has acquainted us with the cells of the medullated sheath, and he concludes that the myelin is enclosed in the meshes of their protoplasm. Towards the sheath of Schwann and the axis-cylinder the protoplasm is thickened to form the inner and outer protoplasmic sheath. When this theory was proposed, Kühne and Ewald had not yet discovered their horny sheath, which probably corresponds to Ranvier's protoplasmic sheath, if neuro-keratine be substituted for protoplasm. I think it probable that from the protoplasm of the young cell, neuro-keratine is formed by differentiation, as is similarly described by Waldeyer in the horny change of the epidermis cells. There, a stroma of keratine threads forms itself out of the protoplasm of the cell, while in its meshes, a fatty substance, eleidin, is deposited. It is difficult to distinguish between the sheath and the framework. Either can be resolved into neuro-keratine. Probably transitions

between the two will be found. I have also tried to convince myself in preparations of the horny sheath, treated by Kühne's method and coloured by hæmatoxylin and nigrosine, whether the neuro-keratine threads really are in connection with the nuclei of the medullated sheaths, and I can assert that one can really see this, so far as it can be observed. Assuming the horny framework of the peripheral nervous system to be a formation of cells, its relation to that of the central nervous system appears all the more assured. For not only the network of the granule layer already described, but also the network of the molecular layer, appears as glia-cells. The connection between both is best observed in the collection of glia-cells to be found at the base of the molecular layer. When from any reason, the molecular and granule layers are separated—which may be caused even by pressure of the cover-glass—there remains one or more layers of cells separated with the molecular layer. The separation occurs below the Purkinje cells, where the unbranched fibres bend round and spread out. Here, the layer of glia-cells attached to the molecular layer forms a membrane, by joining their processes, to support both the fibres and blood-vessels spread out under it, and the Purkinje cells resting on it, and to form also the groundwork of the molecular substance. In Fig. 2 *b*, this is shown in section. Its cells are generally larger than those of the granule layer, as are also their protoplasm and processes, which here become very distinct. Many are pyramidal or pear-shaped, with their broader basis turned to the granule layer, and form, with the long processes given off from the glia-nets of the granule layer, that membrane of the molecular layer which may be represented as a flat network broken up by the cells interspersed in its meshes. Through this membrane pass all the numerous formations on their way from the granule to the molecular layer, and vice versâ. As the name of *limitans externa* has been adopted by Henle and Merkel for the layer of the glia-nets which is in contact with the pia mater, and this layer, by its formation and origin being completely analogous to the above-mentioned membrane on the inner surface of the molecular layer, I propose to call the latter *limitans interna*. Some of the processes from its cells, which are vertical to the limitans interna and go off from the apex of the cells, are particularly thick and can be traced far into the glia-network; and at regular intervals these processes are still thicker and reach to the limitans externa, to which they are attached by a flattened pedicle and serve as supporting pillars to the molecular layer. These were discovered by Bergmann and described by Henle and Merkel. They have also described the limitans externa as a special membrane, separable from the pia mater, and consisting of glia threads. Obersteiner has described one or two cell layers under the pia mater in the new-born animal, from which layers is developed the limitans externa, as well as the supporting pillars; probably the limitans externa has the same character in the new-born as the limitans interna in the adult, so that the pedicles are remains of pyramidal cells, whose apex processes formed supporting pillars

and basal processes the network of the limitans externa. The network between the membrane is also probably the remains of the cells described by Obersteiner, as filling up the embryonal molecular layer, and which have been absorbed with the growth of the network; as the network is too extended to have been formed from the supporting fibres, or from the glia-cells scattered in the molecular layer. Perhaps the protoplasm of the embryonal cells may have been converted into neuro-keratine. Two further points about the glia-cells remain to be discussed. (1) Their relation to the ganglion cells and their processes; (2) their relation to the connective tissue.

(1) We have already mentioned that the glia-cells are accumulated round the ganglion cells (see Fig. 2 *b*). Whilst the ganglion cells at their lower part rest on the limitans interna, they are packed at the sides by these heaped up glia-cells, so that the cells, together with the limiting membrane, closely surround a hollow in which the ganglion cell lies. At the upper and lower part the processes pass out. This walling-in is seen best when the Purkinje cell has been detached from its space, which is then seen spun over with a network of fine fibres, which are continued at the sides into the bodies of the glia-cells. This capsule is thus formed by a net of neuro-keratine threads, supported by a denser accumulation of cells similar to that found in the limitans interna. A somewhat similar capsule has been described by Denissenko and by former authors. Of course such a capsule consisting of a network will allow the cell a free connection on all sides; there is, however, a special condition for the axis cylinder and the protoplasmic processes. The former seems to acquire a continuation of this capsule as a sheath, which is connected with the medullated sheath of the nerve-fibre. But I have no definite drawings on this point. As is evident from Fig. 2, *b*, *c*, everywhere in the course of the protoplasmic processes the glia-nets surrounding them become thickened, so that numerous threads seem to be attached to them, whilst on each side, the meshes of the glia-nets become larger. This attachment of glia-threads has been described by Hadlich and other authors, who state that the protoplasmic processes appear rough, or that extremely fine threads go off from them laterally.

This attachment is however only apparent; it is in reality only a tube-like thickening of the network around these processes, forming a sheath of neuro-keratine threads, continuous with the capsule of the ganglion cells. This appearance resembles the axis-cylinder of the peripheral nerve fibre (when treated according to Kühne's method), which is closely surrounded by a thickening of the horny structure, decribed by Kühne as the inner horny sheath, and here the keratine threads often seem to join the axis-cylinder itself. The broad meshes of the glia-nets on the sides of the protoplasm processes correspond to the space between the inner and outer horny sheaths, which is also traversed by a few threads. A formation analogous to the outer horny sheath is absent in the glia. The resemblance between the relation of the protoplasmic process to its glia, and the relation of the axis-cylinder to its horny

sheath helps very much the comprehension of the central nervous system. But the sheaths in the glia are not isolated, they are in connection everywhere, and are only interrupted by the branching out of the processes. In the glia, the horny component part is unduly in excess of the thread network, as compared with the fatty part enclosed in the meshes : and the fatty substance is not identical with myelin of the peripheral nerves. As Weigert's reaction is only sometimes shown, probably different gradations of myeline exist in the nerve-fibres of the periphery and in those of the central nervous system, where varicose fibres occur, increasing as they become finer.

(2) It is not easy to establish the boundary between the glia and the connective tissue. When they were still unconditionally classed together, it was observed that there by no means existed an immediate connection between the pia and the glia lying under it. Henle and Merkel—who in their treatise assume that glia, nerve elements and connective tissue are produced out of the same materials —describe, however, that the glia limits itself by a lamina limitans externa, and that this is easily detached from the pia, being separated by spaces traversed by single threads,—subarachnoid lymph spaces. A retraction of the glia from the connective tissue sheaths of the vessels leads to the production of the peri-vascular spaces. The glia therefore is only in connection at single points with the connective tissue, which is necessary to give support to the whole framework. In short there seem to be connecting-fibres only between the pia and the limitans externa, as these fibres do not sink deeper into the glia-network.

The connective tissue of the pia may be compared with the Schwann sheath of the peripheral nerves, if the glia be compared with the medullated sheath ; and as between the Schwann primitive sheath, and the medullated sheath, so between the connective tissue and the glia, there exists only a loose connection ; from this it does not follow that the glia might not histologically be reckoned with connective tissue. But this depends entirely on whether or no the glia-cells are descended from epithelium cells of the ectoderm, for our present classification of the tissue is essentially generic. From the above, it is no longer possible to treat of the glia as an undefined boundary between nervous and connective tissue. We have then in the nervous system three distinct systems lying close together :

1. Axis cylinders.	Ganglion cells.	Protoplasm processes.
2. Medullated sheaths.	Glia-cells.	Glia net-works.
3. Schwann's sheath.	Pia mater.	Connective tissue-sheath.

Of these systems the first only can be designated as nervous.

b. The Nervous elements.—One link in the chain of this nervous system fails us. The branched processes of the Purkinje cells must enter again into connection with nerve fibres. It is easy to trace the branches to close to the limitans externa, but here every direct trace is lost. Rindfleisch and Stricker suppose them to become lost in the ground-substance of the neuroglia, but

this has been very much contested, as it is against the physiological demand for a definite course. In my preparations I find no indication of a connection of the ganglion-cell processes with the threads of the glia network. A second view makes the processes end in peculiar nuclei, which lie at the periphery of the molecular layer. I have found it difficult to discover what form of cells Denissenko means by these peripheral nuclei, for at the limitans externa or towards the inner part of the periphery, there are very few cells to be found in the adult animal. Numerous cells are present in the young animal only. Denissenko calls these cells nuclei, and yet states that they are very little coloured by nuclei staining fluids, and further, that in some animals, fibres spring from them which penetrate vertically the molecular layer. The latter fibres correspond to the supporting fibres of the glia, and I consider that the so-called peripheral nuclei are the pedicles with which the supporting fibres attach themselves to the limitans externa. The degree of coloration mentioned by Denissenko agrees also with these pedicles, which might also be called nuclei, as they are possibly the remains of cells; but with the processes of the Purkinje cells these pedicles are not connected.

This view of Denissenko agrees with Golgi's, who makes the processes of the ganglion cells end in connective tissue corpuscles at the periphery, which Denissenko even conjectures to be partly identical with his peripheral nuclei. With the exception of the sheaths of the vessels, I must decidedly dispute the presence of real connective tissue corpuscles at the periphery of the molecular substance on the inner side of the limitans externa. A third view makes the processes of the periphery bend round and run back to the granule layer; and to prove this, certain fine straight fibres, which traverse the molecular layer vertically to the periphery, have been pointed out as these processes (Boll); but the greater number of these fibres can be traced to the limitans externa where they end in pedicles. They are the supporting fibres, as others have already shown.

Lastly, Hadlich has suggested that the ganglion cell processes return again in the same form. This appears at first difficult to contradict, as the processes may be either running out or returning. But Hadlich has already conjectured that there might be two kinds of nerve-fibres, one entering into connection with the axis cylinder of Purkinje's cells, the other with the already mentioned returning branched processes. The latter therefore would not return to ganglion cells, but join directly with nerve fibres. In this way we have a distinct criterion by which to recognise the out-going from the ingoing fibres, and a proof of whether they really exist. I have looked through my preparations and found that there are numerous places where, in the deeper parts of the molecular layer, all ganglion cell processes can be traced to their corresponding Purkinje cells. This precludes the possibility that the protoplasmic processes, after spreading themselves out at the periphery, should collect together and return in the same form to the granule layer, to join with nerve-fibres. Another hypothesis assumes that the returning processes

reassemble in the ganglion cells, of which there are two kinds, and which are not to be distinguished in their outward appearance. But this is contradicted by the fact that the branched medullated fibres can be traced far into the molecular layer. The object of these fibres could not be seen, if the protoplasmic processes return to a ganglion cell lying at the border of the granule layer before joining the nerve fibres. Besides this the number of unbranched fibres is probably just as large as that of the ganglion cells, so that we can drop the hypothesis of two kinds of ganglion cells. If the number of the unbranched fibres is just as many as the Purkinje cells, and if they end at the granule layer, whilst the branched fibres extend into the molecular layer, the probability becomes very great that this cell is in connection with both kinds of fibres, with those in the granule layer by its axis cylinder process, with the others in the molecular by its branched protoplasmic processes.

Fig. 3 is drawn from a section cut parallel to the surface, and therefore at right angles to the direction of sections hitherto shown. The drawing represents the bottom of a sulcus, so that not only the molecular layer, but also the Purkinje cells and a portion of the granule layer are visible on each side. The medullated fibres appear on the flat surface of the section, running in two directions at right angles to each other, and round the Purkinje cells are numerous fibres passing into the molecular layer. The section here given is very thin, or else the fibres would be very numerous, as is the case in thick sections, where it is difficult to see individual fibres. This horizontal plexus is most dense in the deeper parts of the molecular layer, around and immediately above the Purkinje cells. But also in the more superficial planes, fibres running in the same direction can be seen, and the better the reaction has succeeded, the further does their region extend. They are all much finer than the unbranched fibres, but of the same calibre as the finer branched fibres. In the corresponding vertical sections of the lobule, fibres are seen in bundles close round the capsule of the Purkinje cells and passing into the molecular layer. Little of the above described horizontal plexus can be seen in these vertical sections, as the one set of fibres is cut across (compare Fig. 2, *b*), while the other runs parallel to the surface. On the other hand there are fibres visible, which descend vertically in the third plane. These are also fine and often run close to the supporting fibres. Generally these cannot be traced further than through half the molecular layer. Beyond that, although erythrophile substance is met with, it is not arranged in the form of fibre sheaths, but in isolated rings, without any connection. Probably these single rings must stand in some relation to the continuation of the system of medullated fibres.

As the connection of the fibres of the molecular layer with the fibres of the second kind in the granule layer is very distinct, we may say that there exists here a fibre system, which, starting as a plexus from the medullary centre, branches through the granule layer, until the finest fibres are lost in the molecular layer, whilst their medullated substance can be traced further than the axis-cylinder.

As regards the connection of the separate elements it is easy to establish the following points of a scheme:

1. *Each unbranched fibre is connected with each Purkinje cell. The axis-cylinder passes into the protoplasm of the cell, the medullated sheath into the glia-like capsule of the cell.*

2. *The axis-cylinder becomes converted into a number of fibrils in the cell, which pass into the branched protoplasmic process. The fibrils run in the process, which is surrounded by a glia-sheath, as completely distinct threads as far as the periphery. In the branching of this process, the numerous fibrils, contained in it where it leaves the cell, are gradually distributed until they become isolated.*

My preparations show that the arrangement of the ganglion cells corresponds to M. Schultze's scheme. Obersteiner has already described this for the Purkinje cells. Sometimes fibrils cross each other at the points where the processes branch.

3. *The fibrils thus isolated bend round at an angle of* 90° (*not* 180°), *spread themselves out in a plane lying parallel to the surface, and re-arranging themselves in definite order as fibres surrounded by a medullated sheath, run, with frequent interchange between the fibres, in the form of a plexus back to the medullary centre.*

This third point of the scheme contains, of course, much that is hypothetical. But there can be little doubt that the fibres of the second system serve to establish somehow a connection with the branched processes of the ganglion cells. To explain why the fibres should not bend at an angle of 180°, instead of 90°, I must refer to Obersteiner's discovery that the protoplasmic processes of the Purkinje cells only spread out in a plane at right angles to the surface, and also to the direction of the lobule and the plane of the medullated fibre layer. On the other hand, the medullated fibres of the molecular layer run in planes parallel to the surface, and at right angles to the planes of the processes. The processes only need now to bend round at an angle of 90° to pass into the plane of the fibres. Certainly other fibres are required which shall turn at an angle of 90° and connect the higher lying planes with the lower, but these fibres would be coarser and medullated. The strictly angular arrangement of the elements of the cerebellum is remarkable, both in the nervous elements and in the supporting structure. The important point is that we do not see the connecting elements between the ends of the protoplasmic processes and the beginning of the nerve fibres; and in the absence of any really decisive result, some other solution of the problem is possible. Perhaps future research will reveal that just at that point where the continuity of the elements is lost, an arrangement intervenes which we cannot now recognise.

Further, there are medullated fibres under the pia mater lying on the limitans externa, broad fibres of a similar character to those of the medullary centre.

The same fibres may be seen passing through the molecular layer in a slanting direction. A second collection of medullated fibres of the same character lies half-way up the molecular substance. Both run parallel to the medullary centre. As these fibres are

only found in a small minority of the lobules, they are probably an aberration of the medullary centre.

Sometimes the Purkinje cells of the same lobule differ in appearance. Some show, as seen in Fig. 2 *b*, a distinct nucleus, with the nucleolar contents surrounded by a ring of nuclear substance, and in the protoplasm, a distinct fibrillous formation which completely fills up the glia-capsule and in the double-staining with nigrosine and säure fuchsin are stained a light grey colour by the former only.

In the other kind a nucleus is hardly to be distinguished, and no fibril-formation ; the cell appears as a homogeneous body which remains dyed by säure fuchsin, even after washing out by alkaline alcohol. The cells and their processes are slightly retracted from the glia, and the relation between the capsule and its sheath is not quite so distinct. It is not probable that there are here two kinds of ganglion cells, as the difference in the cells is only seen in some of the lobules. It is hardly due either to different action of the hardening re-agent or to the fact of one cell dying before the other, as an external influence would act differently on the cells of two distant lobules, but not on those of the same lobule. We must conclude that the condition of cells must have originally been different at the moment of death.

EXPLANATION OF THE PLATES.

α Unbranched broad nerve-fibres of the first kind.
α' Purkinje's cells.
α'' Their protoplasmic processes.
α''' Branched fibres of the second kind.
β Glia-cells of the granule layer (granules, glia-cells).
β' Cells of the membrana limitans interna.
β'' Supporting fibres (long radiating processes of the glia-cells).
β''' Glia network (short branched processes of the glia-cells).
β'''' Membrana limitans externa.
γ Pia Mater.
δ Non-nucleated structures of the granule layer, stained by Eocene and Nigrosin (Eocene-cells).

GENERAL VIEW MAGNIFIED WITH A LOW POWER.

Fig. 1. Longitudinal section of a lobule from the cerebellar cortex. Medullary centre—internal or granule layer—external or molecular layer. The pia mater with its blood-vessels is slightly separated. Shows the radiation of the unbranched fibres from the medullary-centre through the granule layer to the Purkinje's cells.

Fig. 2. Details of the same section seen by a higher power ($\frac{1}{18}$ oil immersion) showing :

a. Granule layer.
b. Boundary between granule and molecular layers.
c. Middle of the molecular layer.
d. Outer part of the molecular layer.

The figs. 2 *a–d* are to be taken in series.

2. *a*, shows fibres of the first kind, α, and of the second kind α''' between the glia-cells, β, and the eocene cells, δ.

2 *b*. A Purkinje's cell, α' with its protoplasmic process, α'' which breaks up into fibrils. The glia-cells of the lamina interna, β', some of them large and rich in protoplasm, are heaped around the Purkinje's cell. The glia network β''' proceeds from the processes of the glia-cells, some supporting fibres β'' are here not seen joining the cells. In the meshes of the glia-nets are seen sections of medullated fibres of the second kind, α''', stained red.

2 b^1. The glia-cells, in the interval between two Purkinje's cells, form by their intimate connection the limitans interna, β'. Some pyramidal-shaped glia-cells are elongated into processes which extend direct to the periphery and form supporting fibres β''.

2 b^2. A Purkinje's cell in the glia capsule. The cell is seen, so as to show clearly its capsule. The threads of the glia are partly visible coursing over the cell.

2 *c*. Glia network in the middle of the molecular layer. Very clear broad trabeculæ of the network, β''', which is traversed by parallel supporting-fibres β'', and also by a branching process from a Purkinje's cell, showing fibrils, α''.

2 c^1. A supporting fibre, β'', in connection with one of the solitary glia-cells found in this region.

2 *d*. The periphery of the lobule, with the limitans externa β''' cut across at right angles, and with the supporting fibres, β'', attached to it by broad pedicles; between them is the glia network.

Fig. 3. Horizontal section (parallel to the surface) through a lobule of the cerebellar cortex near the boundary between the molecular and granule layers, which is depicted at the periphery of the drawing, so that the Purkinje's cells appear surrounded by medullated fibres of the second kind which having reached the molecular layer, spread out in the plane of the section, in two directions at right angles to each other.

These plates are faithful representations of the preparations, and are not in any way schematic.

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Fig. 1.

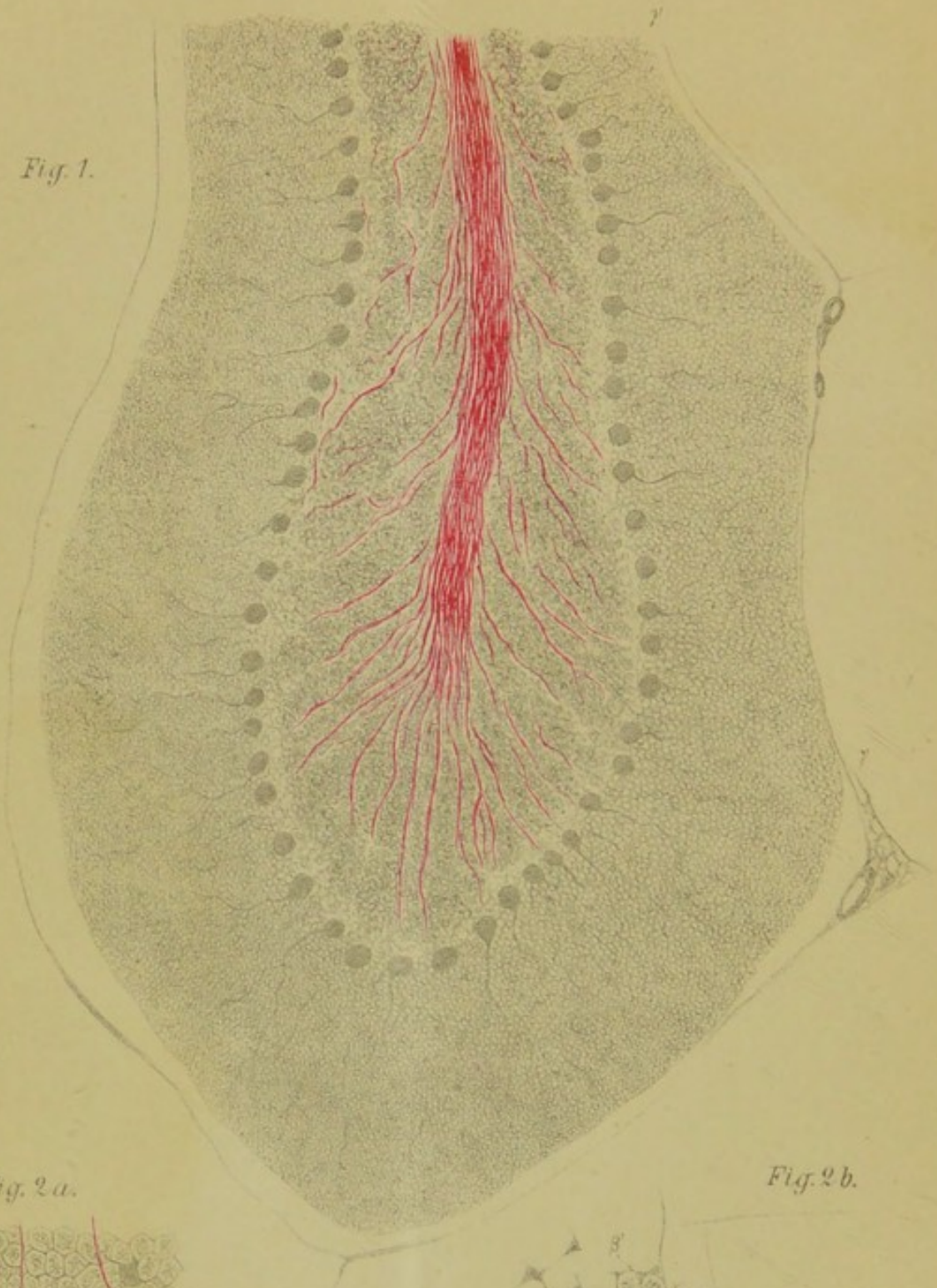

Fig. 2 a.

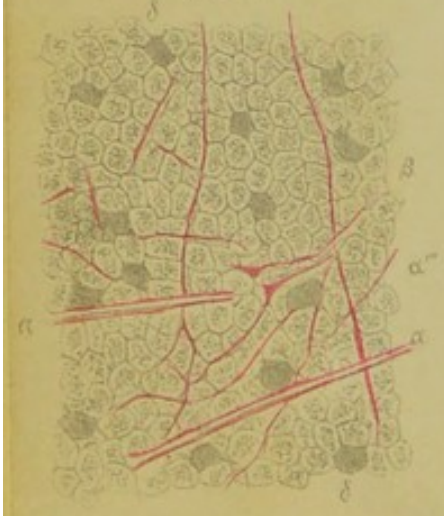

Fig. 2 b.

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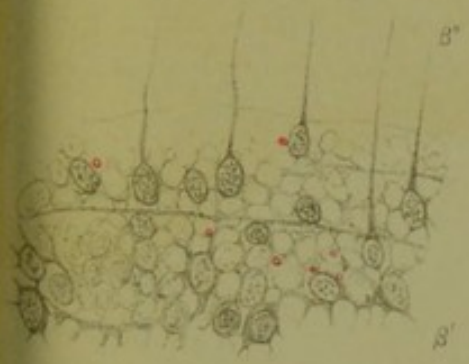


Fig. 2b¹.

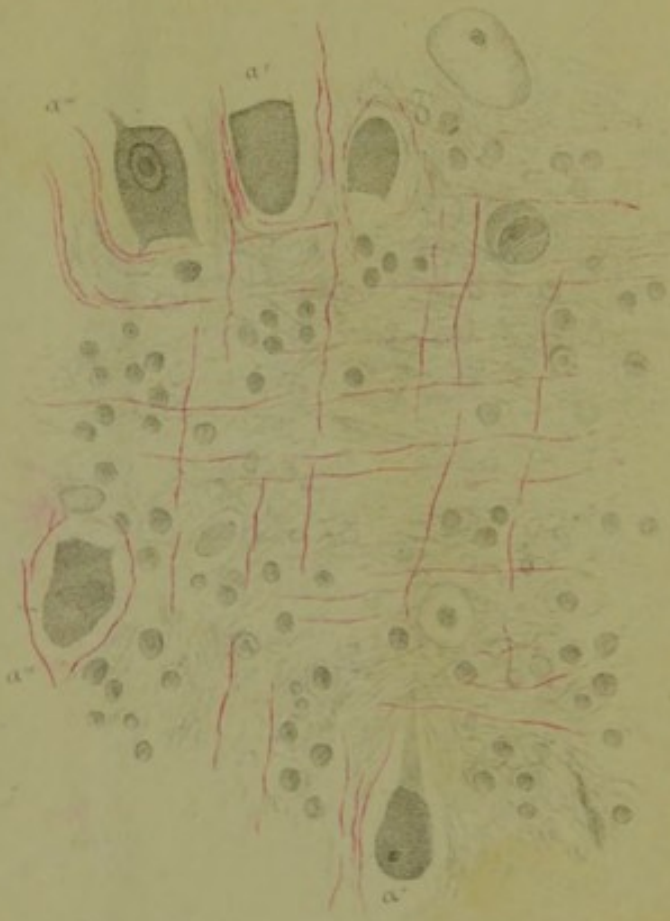


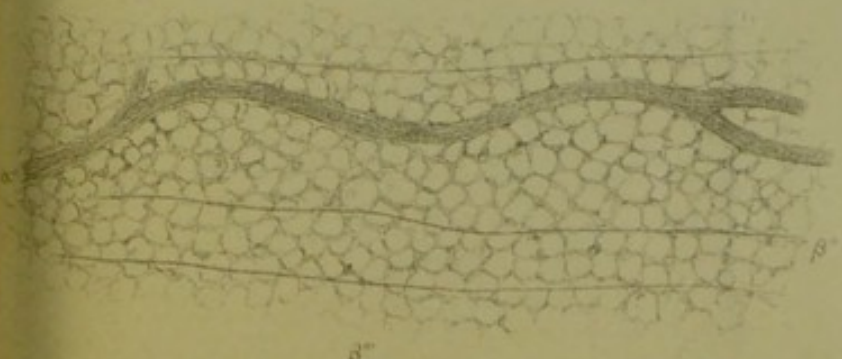
Fig. 3.

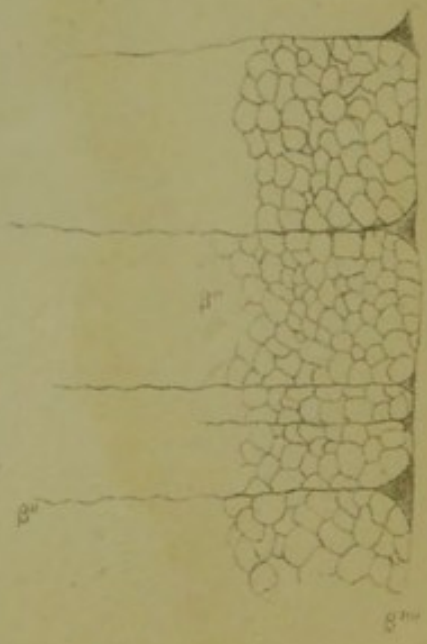
Fig. 2c¹.

Fig. 2b².

Fig. 2c.

Fig. 2d.





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