PROCEEDINGS
OF THE
ROYAL SOCIETY OF EDINBURGH.

VOL. XIV.

1886-87.

No. 125.

On the Conducting Paths between the Cortex of the Brain and the Lower Centres in relation to Physiology and Pathology. By D. J. Hamilton, M.B., F.R.C.S. Edin., F.R.S.E., Professor of Pathology, University of Aberdeen. (Plates XIV., XV.)

(Read 31st January 1887.)

Methods.—The great difficulties heretofore encountered in investigating the course of nerve fibres in the brain have been, firstly, the want of a method of preparation by which their gross anatomy could be thoroughly exposed, and, secondly, the failure of any previously known process of staining to satisfactorily indicate their direction on microscopic examination. In endeavouring to collect reliable data from the records of lesions of the human brain, it becomes only too evident that until more efficient methods of localising lesions be adopted than those generally in use at the present day, little can possibly be added to the knowledge we already possess.

The methods of preparation I now employ for demonstrating the connections of the brain are chiefly the *gelatine-potash* process I formerly described in the *Journal of Anatomy and Physiology* (vol. xix., 1885, p. 385), along with a modification of Weigert's hæmatoxyline-copper stain for medullated nerve fibres lately published by me in the same periodical (vol. xxi., 1887, p. 444).

VOL. XIV.

15/5/88

2 L

The former method is suited solely for naked eye observation. The main objection to Weigert's stain is, as mentioned by its author, that it cannot be adapted to cutting the tissue in the freezing microtome. The modification above referred to has been introduced with the view of overcoming this. The reaction of the nerve-medulla is quite as intense if not more so than that obtainable by the original procedure.

Could one unite the aniline-black stain of Sankey and Lewis for nerve cells with this modification of Weigert's stain for nerve fibres, little would remain to be desired for microscopic demonstration. The difficulty, however, is that the aniline-black dye will give its proper reaction only when the brain is perfectly fresh, whereas the hæmatoxyline will act upon the nerve-medulla only when it has been hardened in a chrome salt. I have, however, already managed to partially combine the two, and see no insuperable barrier to complete success.

The Callosal Fibres.—It is, I think, almost universally believed at the present day that the corpus callosum is a commissure; that anatomically it unites equivalent areas in the two cerebral hemispheres, and that physiologically it serves to bring these into functional harmony. Some years ago, when working at the pathology of the brain, I came upon certain appearances which tended to shake my belief in the commissural theory, and which led to an inquiry, part of the results of which is embodied in this paper. The appearances alluded to are to be seen in the brain of any mammal when it has been hardened in Müller's fluid, but best in those in which the organ is of large size, as in Man. It was in Man that I first noticed the appearance, but I have since then found that it exists in all the mammalian brains I have examined. The Müller's fluid, in the case of a large brain such as that of Man, must be injected from the main vessels at the base in order to insure that it will penetrate deeply and in sufficient quantity.

If such a brain, when completely hardened, be simply cut into a series of perpendicular transverse segments, each of about half an inch in thickness, the following can be readily seen with the naked eye or with a simple lens:—

Coming out of the corpus callosum at each side is a *large arched*

mass of fibres (see Pl. XIV. fig. 1), which leaving this body and continuous with it turns upwards, outwards, and downwards in the centrum ovale. The arcuate mass varies somewhat in shape at different parts of the brain. Thus, anteriorly it represents an almost complete semicircle, while posteriorly it becomes more pointed. The fibres entering into the composition of the arched mass subsequently pass into the inner and outer capsules. The greater bulk of them, however, enters the inner capsule, and in its anterior limb the capsule is almost entirely composed of them; while a considerable portion also seems to run into the outer capsule, constituting the inner of the two layers of which it consists. Their further course and attachments to underlying parts will be subsequently considered.

In a former paper (*Journal of Anatomy and Physiology*, vol. xix., 1885, p. 385) I have named this mass of fibres the "crossed callosal tract"; and as all my work since then has tended to fully bear out the view I at that time entertained of its significance, I propose still to adhere to this nomenclature.

In order to get at once to the gist of the arguments I intend using to explain the nature of this crossed callosal tract, I shall start with the postulate that it is mainly composed of callosal fibres which have arisen from the cortex, which have crossed in the corpus callosum, and which, instead of turning upwards to become attached to points in the opposite cortex corresponding with those from which they sprang, are now turning downwards into the two capsules to become subsequently united to the basal or other ganglia presently to be enumerated.

If it be true that the crossed callosal tract represents the fibres derived from the opposite cortex, which have passed over in the corpus callosum, and which are now turning down to the two capsules, the following data ought to admit of verification :—

1. The crossed callosal tract ought to be capable of being dissected out;
2. It ought to be co-extensive with the corpus callosum; and
3. It should be possible to trace the fibres microscopically as they turn downwards.

I shall consider each of these in order.

1. Foville long ago ("Traité complet de l'Anatomie, de la Physiologie, et de la Pathologie du Système Nerveux Cérébro-spinal," *Atlas*) showed that an arched ridge of fibres could be exposed by simple dissection turning downwards at each side of the corpus callosum, and figured appearances which, allowing for a certain amount of artistic embellishment, substantially represent what actually exists. (The author here exhibited a brain, previously hardened in Müller's fluid, in which this dissection had been made, and in which the arcuate mass of fibres was distinctly displayed. He further showed this arcuate mass in horizontal sections prepared by his gelatine-potash method, in which it was quite clearly mapped out. Its fibres had a more or less transverse direction, so that they contrasted with those coming from the cortex, and the outer border of the mass where they turn downwards was quite sharply differentiated. The fact that the arcuate mass is seen on horizontal section completely does away with the notion that Foville's dissection was artificial. In a series of horizontal sections the crest of the ridge was found to correspond in position with that in the dissection, the site of it being at a point considerably below the level of the cortex at the vertex.)

2. That the crossed callosal tract is co-extensive with the corpus callosum can be proved by dissecting it out, or by examining it in a horizontal gelatine-potash preparation.

3. To trace microscopically the fibres curving downwards from the corpus callosum is not such an easy matter as might be supposed, owing in great part to the fibres running in different planes between their points of origin and insertion.

Meynert has alleged that he could trace single fibres from the cortex of one side through the corpus callosum into the cortex of the opposite. For my own part I can hardly credit this statement, for, after having spent an immense deal of labour upon the subject, and working with methods far more refined than those employed by Meynert, it has never been my good fortune to follow a single axis cylinder from the one side to the other even in the smallest mammals. The fibres diverge and run so obliquely after crossing that I question if a section made in any one plane would suffice to expose their entire course.

If the brain be cut *perpendicularly in an oblique antero-posterior*

direction, however, the bundles of callosal nerve fibres can be traced from about the middle line continuously down to the outer and inner capsules, instead of upwards to the cortex as generally asserted. In Pl. XV. fig. 2 I have given an accurate drawing of a section of the human brain ($\times 10$ diams.), stained and prepared by my modification of Weigert's method, and taken from a region corresponding to the front of the basal ganglia. The parts of the preparation included in the drawing are the tectorial part of the corpus callosum (*c.c.*), the crossed callosal tract (*c.c.t.*), the plexiform nucleus (*p.n.*),* the head of the caudate nucleus (*c.n.*), and the inner capsule (*i.c.*). The section from which the drawing was taken was made perpendicularly in the oblique antero-posterior direction just indicated. By so doing the continuity of a certain number of callosal fibres, as will be noticed, can be followed in a direction downwards, although it will be remarked that even here some of them (as at *s.c.f.*) have been obliquely divided.

From the drawing it is evident that the bulk of the fibres issuing from the side of the tectorial part (*c.c.*) of the corpus callosum sweep distinctly upwards, outwards, and downwards towards the inner capsule (*i.c.*). They are united in coarse bundles, and thus can be readily distinguished from those entering it (*v.c.f.* and *p.n.f.*), which, although in bundles, are less condensed, and which, moreover, spread out in a radiate or fan-shaped manner. When the brain is cut in a perpendicular *transverse* direction the continuity of these fibres cannot be seen, because they have been severed by lying at an angle to the plane of section. Hence it is, I believe, that they have remained so long unnoticed. In no case have I been able to see a single bundle of fibres run upwards after emerging. After having crossed, the whole mass seems to turn downwards to the capsules, and to form the greater part of their bulk.

In two late numbers of *Brain* (vols. viii. and ix.), Dr Beevor has taken exception to this view as originally enunciated by me in a communication to the Royal Society (*Proceedings*, No. 230, 1884), and in papers which I subsequently published in the *Journal of Anatomy and Physiology* (*loc. cit.*), in *Brain* (vol. viii., 1886, p. 145), and elsewhere. He says that in the marmoset he has been unable to see the fibres turning downwards in the manner I

* For description of this body see the sequel.

have described, and gives a drawing which he considers demonstrates that my view is wrong, and that the old idea of the fibres passing from cortex to cortex is correct.* He asserts that this drawing is not a diagrammatic scheme, but an actual representation of a preparation in his possession. He further states that he has made oblique sections as I had directed, but still has been unable to see what I described.

When I read this criticism, I felt certain of two things: first, that Dr Beevor had not examined preparations cut in the oblique direction I have recommended; and, secondly, that the drawing above referred to was not an actual representation of the preparation from which it was said to have been taken. I was convinced that what he had endeavoured to depict consisted in reality of the fibres *passing into* the corpus callosum, and that he had entirely failed to see, as had happened to others, those which were *issuing from it*, owing to his having cut the brain transversely instead of obliquely. In justice to Dr Beevor's statement, however, I resolved to see his preparations for myself, and to hear his explanation of them by word of mouth. I am constantly being reminded by so-called critics that they are still sceptical of my statements, and the most ardent are those who have never taken the trouble to examine my work, nor really to work at the subject for themselves. The matter is not one which can be settled in an offhand manner, but requires the most careful scrutiny. If it had been easy to demonstrate what I have recorded, it would long ago have been done.

My anticipations in regard to the basis on which Dr Beevor's criticism was founded were more than realised. I emphatically state that the drawing of the corpus callosum given in his critique in *Brain* (vol. ix.) is very far from being an actual representation of the preparation from which it was taken. The continuity of the fibres is not such as he depicts, for immediately at the outer margin of the corpus callosum there is a break in the preparation caused by a large number of fibres having been cut off abruptly, which is not represented in the drawing. The fibres so cut across constitute those I have described as turning downwards. They have been severed, because they do not lie in the same plane as those

* Ferrier, I find, has somewhat hastily reiterated this statement in the latest edition of his work on the *Functions of the Brain*.

entering the body. I further found that the oblique preparations he employed had been cut in an entirely wrong direction, in a direction which was calculated to divide the crossed callosal fibres, instead of rendering them more apparent. As I have elsewhere stated, he has not followed the directions I have so explicitly given in various of my published papers, and hence it is useless to argue the point. If he will harden the human brain, or, say, that of a sheep, by the method I have recommended, and cut this perpendicularly in an oblique antero-posterior direction, he will see what I have described. It is impossible, as I have already indicated, to trace individual axis-cylinders throughout their entire course, but the continuity of individual bundles between the corpus callosum and the capsules can be demonstrated with facility. The difficulty of tracing the course of the crossed callosal fibres rests in this, that *those which lie anteriorly after crossing run obliquely backwards, while those which lie posteriorly run obliquely forwards*, the point to which they all tend to converge being the knee of the inner capsule.

It consequently happens that in whatever plane the organ may be cut, the fibres will be divided at some point. In a completely transverse perpendicular section the crossed callosal fibres are usually divided, and being represented only by small fragments, are very apt to be overlooked in the dense mass of nerve-medulla lying in their neighbourhood.

The Cortical Plexuses.—Of late years a good deal has been written of the most interesting plexus of medullated fibres which exists in the cortex of the cerebellum and cerebrum, by Exner (*Sitzungsb. d. k. Akademie d. Wissensch.*, vol. lxxxiii. Ab. iii., Feb. 1881), Butzke (*Arch. f. Psychiatrie*, vol. iii., 1872), Gerlach (*Centralb. f. d. med. Wissensch.*, 1872, p. 273), Boll (*Arch. f. Psychiatrie*, vol. iv., 1874, p. 1), Rindfleisch (*M. Schultze's Arch. f. mik. Anat.*, vol. viii. p. 453), and others. It seems likely, as Hill suggests, that since the discovery of these fine cortical plexuses our whole notions of what are known as *nerve centres*, and of the communication that exists between nerve cells and fibres, will shortly be revolutionised. The plexuses to which I refer can be seen only when certain methods of staining are employed. Exner, who is generally regarded as having discovered the plexus in the cerebral cortex,

employed perosmic acid and ammonia, but since then the reagent used for the purpose of demonstrating it has almost exclusively been Weigert's hæmatoxyline dye previously referred to.* In the cortex of the cerebellum the plexus is probably densest, but it is present in all parts of the cerebral cortex as well.

Continuity of Cortical Plexus with that in White Matter.—What I would specially wish to direct attention to at present, however, is that this plexus not only prevails in the cortical grey matter, but that it appears to intertwine itself round the nerve fibres throughout a great part of the white. The large medullated nerve fibres from the cortex run into the white matter, but almost immediately become surrounded by a dense padding or casing of this nerve network. At first it might be supposed to be simply connective tissue, and it has in bygone times been always regarded, when indistinctly seen by less favourable means of demonstration, simply as the branching neuroglia. The plexus I refer to, however, as pervading the white matter of the brain is a true nerve structure, and that which is found in the cortex of the cerebrum and cerebellum is an extension or outcrop of this. The appearance presented by it a short way within the cortical grey matter, of the motor region, towards the vertex is shown in Pl. XV. fig. 3. The large medullated trunks (*a., a.*) are seen coming down from the grey cortex, but shortly after penetrating into the white matter of the centrum ovale they become encased, as it were, in a dense and complex mass of medullated fibres (*d.*). Between its fibres is the granular neuroglia (*c.*), which seems to fill all the meshes formed by it.

The Plexiform Nucleus.—A similar medullated plexus also exists in certain of the ganglia, such as the thalamus and lenticular nucleus. In the former it is in a high state of development, but there is one part of the brain in which it reaches even a higher grade of complexity. I refer to a little comma-shaped body (fig. 2, *p.n.*) which lies in the angle constituted by the under aspect of the tectorial part of the corpus callosum and the upper surface of the caudate nucleus. This body, whose presence I do not remember having seen referred to, is one mass of a dense and complicated nerve plexus, and, so far as I am able to discover, is without nerve cells. It

* Since this paper was read various modifications of Exner's method have been introduced by Pal of Vienna and others.

is contiguous to the caudate nucleus below, but the tissue of the one is separated from that of the other by a sharp line of demarcation. It passes for a short way underneath the corpus callosum, and at its lower extremity posteriorly, seems to be united with the tænia semicircularis. Its fibres are directly continuous with the fibres of the plexus in the white matter just referred to. It is most developed anteriorly in the region of the head of the caudate nucleus.

In Pl. XIV. fig. 4 I have given a drawing of the plexus constituting this body as it appears when magnified about 350 diameters. The part from which the drawing was taken was immediately adjacent to the inner capsule at the point *x*. in fig. 2. The plexiform nucleus (*p.n.*, *p.n.*, *p.n.*) is seen to the right; a few of the fibres of the inner capsule (*i.c.*) to the left. It will be noticed that the main bulk of the body is made up of an intertwining felt-work of nerve fibres. They stain deeply with Weigert's copper-hæmatoxyline dye, and between them, as in other regions of the brain, a quantity of granular neuroglia is interposed. It is only lately that I have made out the true nature of this body, and on account of its structure I propose to name it the *plexiform nucleus*.

Points of Origin of the Callosal Fibres.—The most of the callosal fibres which come down from the *vertex* appear to run *directly* into the corpus callosum. Their usual appearance and direction are represented in fig. 2 (*v.c.f.*, *v.c.f.*). In passing downwards they interlace with those leaving the corpus callosum, and which are turning downwards to the two capsules.

Those, however, which are derived from the lower third or half of the cortex between the Sylvian fossa and the great longitudinal fissure (fig. 2, *p.n.f.*, *p.n.f.*) do not appear to run directly into the corpus callosum, but pass first of all into the *plexiform nucleus* just described. Shortly after issuing from the grey matter they become united into loose bundles which penetrate through the fibres of the crossed callosal tract, and which seem to lose themselves within the *plexiform nucleus* by breaking up into its reticular network. From this reticular network fresh fibres appear to arise, and to enter the corpus callosum. In all probability, these turn downwards on the opposite side into the two capsules as fibres of the crossed callosal tract. This *plexiform nucleus* would thus possibly represent

a meeting-point for many of the callosal fibres before they proceed to cross, the individual fibres losing their identity within it by splitting into an anastomosing common network, from which again fresh fibres appear to arise and travel across the corpus callosum to the opposite side.

The fibres which enter this body are chiefly derived from the motor centres which in Man have been found to preside over the muscles of the tongue and face, that is to say, the lower parts of the ascending frontal and parietal convolutions, and it is conceivable that the function of the plexus contained in it is to correlate and associate their action.

Destinations of the Callosal Fibres.—After passing into the inner and outer capsules, the arched callosal fibres just described become united into dense bundles. A very large proportion of them lose themselves in the *thalamus opticus*. The excessively fibrous appearance which the thalamus presents is due to these fibres passing into it. They probably break up into a network, in the meshes of which the nerve cells are intercalated.

Are these nerve cells directly connected with the nerve fibres entering the ganglion, or is the network referred to intermediate? It seems more likely that the union is not direct, but that a plexus intervenes between the two, and that this plexus simply surrounds the nerve cells. I am even not at all convinced that the processes of the nerve cells are in all cases directly connected with the plexus. May not nerve energy generated in cells exert its influence upon nerve fibres in ways other than by direct continuity? Is it not possible that it may be transferred to the coils of a dense plexus through the liquid and neuroglia which fill up the intervals in the tissue, and that, conversely, peripheral stimuli may thus be conveyed to a nerve cell? I think this is at least conceivable, and the idea has of late been entertained by several physiologists, both in this country and abroad.

Few, if any, callosal fibres end in the *caudate nucleus*, and, curiously, as if supporting this observation, the plexus in this ganglion seems to be very scanty. The *lenticular nucleus* may receive through the *striæ medullares* a considerable number, and probably some of the fibres connected with the *red nucleus* may be also callosal. A large number appear to end in the *pons and medulla*

oblongata, while there is a probability of certain of them even extending down to the *spinal cord*.

The Direct Fibres.—This paper, however, is concerned with the connections between the cerebral cortex and the centres lower down, and as yet I have referred to only one set, namely, those which are callosal and which cross from the opposite side. There are others, of course, which run down directly, and of these the motor fibres are among the most important. These direct motor fibres lie to the *outside* of the crossed callosal tract (fig. 2, *d.f.*), and, like it, bend somewhat outwards in circumventing the ventricle. Those derived from the *marginal gyrus* seem, at least in the sheep, to lie in very close apposition with the fibres of the crossed callosal tract. In Man I calculate that about one-third of the fibres entering the anterior two-thirds of the posterior limb of the inner capsule are direct, while the remainder are crossed callosal.

From experiments made upon the cortex, it is evident that these direct fibres are derived from a wide area, one, indeed, so wide that it comes to be a question how it is that they are so few in number when they decussate in the medulla and become connected directly, or through the intermediation of the spinal cord, with the peripheral nerves. The notion at present held by most physiologists is that from the motor cells of the cortex fibres issue which are continuously prolonged downwards to the spinal cord. But if we consider the matter for a moment, it is evident that they must have been much reduced in bulk by the time they have reached the medulla, and that the pyramidal fibres of the medulla or cord cannot represent the whole of the motor fibres derived from the motor area. How, then, is this sudden falling off to be accounted for? My present conviction is that the direct continuity of the process of a ganglion motor cell in the cortex with the pyramidal tracts of the spinal cord is a myth. I am strongly inclined to believe that, just as in the case of many of the callosal fibres, the motor fibres break up into a plexus, from which again fresh fibres, those which enter the pyramidal tracts, take their origin. When the pyramidal tracts in the cord are affected by secondary degeneration, they are mapped out with the utmost precision, and the degeneration never overlaps them. Can the same be said of the degeneration further up in the centrum ovale? I do not think that

it can. There is always more or less diffusion of the tract immediately and for some distance below the point of lesion, if that be cortical, and the explanation I think is to be found in the interposition of this plexus. The plexus is a means of reduction and association, a means by which the action of the many fibres coming from a particular cortical area may be combined and correlated in the few.

But the direct fibres entering the inner capsule are not all motor in their function. There are many other bands which enter it and whose function varies. Thus there is a large contingent of fibres which passes into its posterior limb from the parieto-occipital region, and whose function, there cannot be much doubt, is sensory. It has been shown, over and over again, that when it is destroyed hemianæsthesia results. Then there is a large band of fibres which comes from the prefrontal region, and which enters the anterior limb on its way back to the anterior nucleus of the thalamus, to which it becomes attached. The geniculate bodies and the pulvinar finally are connected by direct bands with the occipital region.

Plexus most abundant in Man.—One of the main differences which exist between the brain of Man and that of the lower mammalian types consists in the disproportional size of the white and grey matters. In Man the white matter is relatively more abundant than in the brain of any other mammal I have examined, and the lower we go in the scale the greater the disproportion appears to be.

Now, the cause of this seems mainly to reside in the fact that this intertwining plexus which ramifies through the whole centrum ovale is vastly more abundant in Man than in the lower animals, and hence, probably, the superiority of the human brain as an instrument of association may be accounted for.

Connections of Thalamus Opticus.—I have said that a large number of callosal fibres pass into the thalamus opticus. They lose themselves in it, apparently by becoming connected with a dense plexus. In conclusion, let me ask the question whether there are any fibres which leave the thalamus, and, if so, where they go to? Do fibres descend from the thalamus into the cerebral peduncle, ultimately to enter the spinal cord? I am becoming daily more and more convinced that, if such do exist, they must be small in

number. Certain bands of fibres which are not callosal, no doubt enter the thalamus, but these seem to connect it with parts of the *cortex* which experiment has shown are associated with definite and well-located functions. Thus there are the three so-called *peduncles* of the thalamus, uniting it respectively with the prefrontal region, with the nucleus amygdalaris in the temporo-sphenoidal lobe, and with the hippocampus major. But these differ entirely in their nature from the fibres which are supposed to leave the thalamus and to pass downwards with the other descending cerebral tracts, and it seems to me that the latter, if they do exist, must be in small quantity.

How, then, is the thalamus connected peripherally, and what is its use? As yet any statement on this subject must necessarily be largely conjectural, but, all things considered, there is reason for at least supposing that this ganglion is largely concerned with the *education* of the brain *through the optic nerves and corpus callosum*. Of all the nerves in the body the optics are those by which the brain is mainly educated. They are in constant use, imperceptibly opening up the cortical grey matter to impressions made upon the periphery by light vibrations. What is the connecting link between the peripheral retina and the central cortex? The visual centre is said to be located in the occipital lobe, but the optic must subserve a far wider function in educating other parts of the cortex as well as this small area? How is it that the motor centres, for instance, are educated to a particular complicated act, purely through the sense of sight? What is the mechanism by which a sudden visual impression, accompanied by a sense of danger, will serve to throw the body instantaneously into a complicated attitude of defence? This introduces far too wide a subject of discussion to take up at present; but it seems to me likely that the callosal fibres entering the thalamus constitute the substratum by which these acts are accomplished; that they are, in fact, the means by which the opposite side of the brain is educated through vision.

Where the corpus callosum has been destroyed in infancy, imbecility seems to have been the invariable result. There are certain records of congenital deficiencies of this body which have been unaccompanied by any symptoms of note, more especially one

described by Eichler (*Arch. f. Psychiat.*, vol. viii. p. 355). It seems, however, that in these cases we have to do not with a deficiency in the actual callosal fibres, but with a malformation by which they have failed to decussate in the middle line, just as so frequently happens in the anterior pyramids.

On the supposition that the thalamus subserves the purpose of concentrating the fibres which educate the higher centres through the optic, it can readily be understood how, if it were destroyed in adult life, no very evident symptoms might follow. It has already to a great extent subserved its purpose. The higher centres have been educated, and are capable of discharging their functions apart from the channels through which that education has been imparted. It has played its part, so to speak, in infancy and youth, and may now in a manner be considered as functionally inert. The impressions made upon the cerebral cortex through it are quite possibly recalled by a perfectly different set of channels; for I do not see why in the internal economy of the brain there may not be paths for *educating* the higher centres through vision, hearing, touch, and so on, and a whole set of other paths by which the results of this education may be brought into action. If such be the case—and I advance this with all due caution—the callosal system of fibres might be regarded as the great *educating system*; while the direct bundles to which I have adverted would constitute the means of adapting this education to a utilitarian purpose.

In the case of those born blind, the education of the cortex would of course be carried on through other channels, namely, through those of the remaining special senses. The nuclei of the nerves connected with these are situated in great part in the pons, medulla oblongata, and spinal cord, and these again, as already mentioned, appear to be extensively united to crossed callosal fibres which have descended in the inner capsule. By the agency of these callosal fibres they are placed in communication with the cerebral cortex on the opposite side of the body. The same mechanism for educating the cortex in fact prevails here as in the case of the optic; that is to say, there is, firstly, the peripheral nerve to receive the impression; secondly, an intermediate nucleus to which the nerve is bound; and, thirdly, a system of fibres (callosal) by means of

which this nucleus is placed in continuity with the opposite cerebral cortex.

The arrangement seems a probable one; all the most important motor and sensory channels seem to cross the middle line at some point. We see this exemplified in its most simple form in the ordinary ascending and descending paths in the spinal cord; and there seems good reason for believing that the same type of construction prevails higher up. The callosal fibres would thus represent the decussation of the multiform tracts which do not cross in any of the commissures or decussations lower down. The greater number of them are probably not motor nor purely sensory in their function, but in great part *educational*. They are, in fact, the means of impressing the opposite cortical centres with the stimuli that have been made upon the intermediate centres lower down.

EXPLANATION OF PLATES XIV., XV.

Fig. 1. Perpendicular opaque transverse section through the region of the infundibulum of human brain hardened by injecting Müller's fluid. Natural size. In the centre is the corpus callosum, and at each side of it, turning upwards, outwards, and downwards in the centrum ovale to the two capsules, is the arched mass of fibres which I have named the *crossed callosal tract*. The fibres *coming in* to the corpus callosum from the cortex of the vertex and elsewhere are seen interlacing with the fibres of this arched mass. The drawing was made with the greatest care, and may be taken as being as nearly as possible a *facsimile* of the preparation from which it was copied. The brain, after being thoroughly hardened, was simply cut into segments about half an inch thick, whose surfaces were polished in the freezing microtome. Nothing further was done to it. The drawing represents the surface of one of these segments.

Fig. 2. Perpendicular oblique antero-posterior section of human brain through the corpus callosum and *crossed callosal tract*. $\times 10-20$ diams. Stained by the author's modification of Weigert's copper-hæmatoxyline process. *c.c.*, corpus callosum; *c.c.t.*, crossed callosal tract; *v.c.f.*, *v.c.f.*, callosal fibres from the vertex; *p.n.f.*, *p.n.f.*, same, from cortex lower down, running towards the plexiform nucleus (*p.n.*); *d.f.*, direct cortical fibres lying outside the crossed callosal tract, and running down to the inner capsule (*i.c.*); *s.c.f.*, severed callosal fibres of the crossed callosal tract; *c.n.*, caudate nucleus; *x.*, part of preparation from which figure 3 was drawn.

Fig. 3. Portion of white matter immediately under the grey mantle of the cortex at the vertex in the motor region. Stained as in figure 2. $\times 300$ diams. *a.*, *a.*, bundles of large medullated fibres passing downwards from the grey matter; *b.*, a clot in a blood-vessel; *c.*, the granular neuroglia; *d.*, the felt-like plexus of nerve fibres surrounding the straight bundles coming from the cortex.

Fig. 4. Part of plexiform nucleus and adjacent inner capsule, taken from the preparation depicted in figure 2 at point *x*. $\times 350$ diams. *p.n., p.n., p.n.*, outer border of plexiform nucleus; *i.c.f., i.c.f.*, descending fibres of inner capsule; *u.c.f., u.c.f.*, cortical fibres derived from the grey matter shortly above the Sylvian fossa, and which apparently end in the nerve network of the plexiform nucleus.

Fig. 4.

Fig. 1.

Fig. 3.