THE GOULSTONIAN LECTURES ON SECONDARY DEGENERATIONS OF THE SPINAL CORD.

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LECTURE III.

DIRECT CEREBELLAR TRACT.

AFTER the posterior median column, the direct cerebellar tract is most constantly degenerated. This tract was figured by Türck, who traced it to the restiform body; but Flechsig was the first, I believe, to suggest its destination in the cerebellum. It is situated in the periphery of the lateral column, and in its fullest development is a thin strip bordering the lateral column, having its largest end against the posterior horns, and thinning off to about the middle of the arc of the lateral column. But its position in this arc appears to vary considerably with the position of the initial lesion and the point at which the section is made from it. It appears that degeneration does not show itself in the site of this tract after lesions of the lumbar region.

Lowest Point of Origin of Direct Cerebellar Tract.—Schultze¹ gives a case of fracture of the ninth dorsal vertebra, causing complete compression of the cord, therefore, at the level of the tenth pair. Here there was an annular degeneration, spreading round the periphery of the section from the posterior horn to the anterior roots. This was continued up to the cervical region.

In the interesting case of Dr. Gowers, described by him first in his "Diagnosis of Diseases of the Spinal Cord,"² the crush was situated at about the eleventh dorsal, and, though the antero-lateral tract was affected, the direct cerebellar was not degenerated at all. From these two observations, then, we may place the lowest point of origin of the fibres in the direct cerebellar tract at somewhere between the ninth and the eleventh dorsal. It is probably usually higher up than this.

Kahler and Pick³ give a list of twenty-seven cases, collected from various authors, of transverse lesions, with the relative frequency of affection of the posterior median and direct cerebellar tracts. In all the posterior median column was affected, and in those above the ninth dorsal the direct cerebellar tract as well. In those in which the lesion was below that point the direct cerebellar tract was not affected.

The lowest case of compression that I have is Case II; here the compressing tumour sprang from the laminae of the sixth, seventh, and eighth dorsal vertebrae. Owing to injury in removing the cord, unfortunately, the sections begin at the first dorsal. Here the direct cerebellar tract is plainly degenerated as a thin strip joining anteriorly with the antero-lateral tract, presently to be described. There are many normal large fibres and a few small; nearly all the degenerated fibres are evidently of the large variety, and therefore, if any of the small fibres are degenerated, they have become absorbed. That large numbers of degenerated fibres have been absorbed is evident from the considerable amount of tissue intervening between what fibres remain, whether degenerated or not. From these facts the obvious inference is that new fibres are coming into the tract from somewhere, and that these are principally large fibres. Anteriorly, the tract expands into the antero-lateral, which contains large numbers of degenerated fibres, both large and small, and very few normal ones at all. The tract retains these characters, but getting smaller and smaller, till we arrive at a section at the level of the fifth cervical, where it is quite distinct from the antero-lateral, and it is gathered up as a small patch against the tip of the posterior horn. Here it is only

to be distinguished from the rest of the lateral column by its lighter colour by Weigert staining, but it contains a large number of normal fibres. At the level of the second cervical, the direct cerebellar tract degeneration has disappeared, except for the presence of one or two isolated fibres. Meanwhile, the antero-lateral remains highly degenerated. It may be said, then, that the direct cerebellar tract, if degenerated secondarily to lesions of the lower dorsal region, is small and tends to disappear soon, that is, before reaching the medulla. If, however, the lesion be high up in the cord, say, in the cervical region, we have a different condition of things.

I must here again refer to the appearances in Case v, Fig. 7, in which the lesion was a fracture-dislocation, involving the cord between the eighth cervical and the first dorsal. One root above the lesion we find degeneration of practically the outer half of the lateral region, an extension of the degeneration round the anterior root-region into the anterior column (Fig. 7, C VII, Lecture II). In fact, there can only be said to be normal fibres in the immediate vicinity of the grey matter. Moreover, the degeneration is absolute except close to the posterior horns, where, of course, normal new fibres are entering, and here perhaps there are some fibres; but, unfortunately, there is so much alteration of the normal parts by decomposition, that exact histological observations are untrustworthy. The condition resembles the annular sclerosis of Charcot. A root higher, namely, the sixth cervical, the same appearances obtain, but the area of degeneration is smaller. At the fourth cervical (Fig. 7, C IV), we have a long strip of degeneration stretching from the posterior horn round the edge of the section, and thinning off to the anterior root. There now appear many normal fibres in the degenerated area. Till we reach the level of the third cervical, we may speak of the degeneration as one slip occupying the periphery of the section; but at this level we discover a tendency, more particularly on the right side, to division of the strip at about its middle by the invasion, as it were, of a mass of normal fibres. The posterior part is the direct cerebellar tract; the anterior, the antero-lateral tract.

At the second cervical (Fig. 7, C II), this division is still more evident on the right side. On the left there can scarcely be said to be any such division at all.

I propose to leave the discussion of the further course of the tract in the medulla oblongata till I have spoken of the antero-lateral tract, because the two bundles of fibres are closely intermingled in the lower part of the medulla.

Origin and Constitution of Direct Cerebellar Tract.—To return to the question of the origin and constitution of the direct cerebellar tract. The fact that degeneration of this bundle does not follow lesions of the lumbar region has been already stated. It is obvious, therefore, that the fibres composing it do not come by way of the posterior roots from the lower extremities. If further proof were necessary, the results of the experimental section of posterior roots above related would supply it, to say nothing of recorded cases of pathological lesions of the same. It has long been suggested that the posterior vesicular column supplies fibres to this tract. Drs. Lockhart Clarke and Gowers have maintained this view on anatomical grounds. In longitudinal section of the natural cord, fibres can be seen passing straight across the lateral column, which appear to pass in the direction of this tract. Another anatomical point in favour of this view is the position and shape of the posterior vesicular column. This column is circular in section, and in man extends from about the eighth dorsal to the second lumbar. But there are a few scattered cells in this situation up as high as the first or second dorsal. They quite disappear in the cervical swelling, to reappear in the upper cervical region, and in the medulla, as already suggested, there are patches of ganglion cells much resembling these in the clavate and cuneate fasciculi. Dr. Ross⁴ has already pointed out that there are nuclei in the vicinity of the central canal in the lower part of the medulla, which may actually be the upward continuation of this column. Now this column contains many ganglion cells, the prevailing type of which is the small, elongated, bipolar variety, but there are also unipolar and larger multipolar cells. This column is admitted by most to be in direct communication with fibres entering by the posterior roots; these can be seen degenerated in monkeys 2 and 4 already described.

Dr. Mott⁵ has described fibres passing from the posterior vesicular column across the lateral column towards the direct cerebellar

¹ Schultze, "Beitrag zur Lehre von der secund. Degen.," etc. *Arch. für Psych.*, 1883, p. 364.

² Afterwards in the *Lancet*, June, 1886, p. 1153.

³ Kahler u. Pick, "Weitere Beiträge zur Pathol. und Path. Anat. der Central Nervensystem." *Arch. für Psych.*, Bd. x, 1880, p. 196.

⁴ Ross, *Dis. of Nervous Syst.*, 1883, vi, p. 791.

⁵ Mott "Microscopical Examination of Clarke's Column in Man, Monkey, and Dog," *Journ. of Anat. and Phys.*, vol. xxii, p. 479.

tract. These, he says, are principally of the large variety. Dr. Mott, in the same paper, records a case of injury to the roots of the cauda equina, with degeneration of the postero-lateral and posterior median columns, but none of the direct cerebellar tract. A careful examination of the posterior vesicular column showed no alteration of the ganglion-cells, but an atrophy of the plexus of fibrillæ, with an increase of nuclei, a condition which I can detect in my monkeys. It must be conceded, then, that there is considerable anatomical evidence in favour of some connection between the posterior vesicular column and the lateral column. Now Dr. Gaskell has given the most convincing reasons for supposing that the posterior vesicular column has intimate connection with the innervation of the visceral system, whether blood-vessels or abdominal viscera it does not matter much for our present purpose. The visceral and vasomotor nerves differ from the ordinary cord-fibres in being of the very finest calibre. It is almost certain that the fibres passing to and from the posterior vesicular column are of this description. Therefore, if they go to the direct cerebellar tract, we should expect that tract to have many of these fibres in it. This brings me to examine the tract in the normal cord, or, rather, to examine the situation in which the tract appears when degenerated.

Anatomical Examination of the Direct Cerebellar Tract.—If we examine carefully the constitution of that part of the lateral region lying close to the tip of the posterior horn in the cervical cord at the level of the first cervical, we find a very great preponderance of large fibres, but there is a very small number of fine medullated fibres scattered about. At the level of the third cervical we may say that this area is practically free from small fibres, so that in the monkey, after staining by carmine, the direct cerebellar tract region looks to the naked eye lighter than the rest of the lateral column, because the latter contains vast numbers of fine fibres much in excess of the large, and therefore stains deeply. This condition obtains as low down as the seventh cervical, where again a small admixture of fine fibres appears. Root by root in the upper dorsal region more and more fine fibres make their appearance in this tract, till at about the sixth dorsal there are nearly as many fine as large fibres. Below this, however, the fine fibres are much in the majority, till in the lower dorsal and lumbar region there can be said to be little else. These observations have been made on monkeys' cords, because we can get the cord immediately after death, and therefore can rely on the histological appearances with certainty. I have little doubt that what I have said applies equally to the human cord. The region of direct cerebellar tract, then, differs in its anatomical structure in the lower dorsal from that in the cervical and upper dorsal regions in that in the former there is a preponderance of small fibres, while in the latter there is a preponderance of large.

But these anatomical differences are confirmed by experiment. In a monkey, which I call monkey 3, Mr. Horsley divided the posterior roots of the sixth, seventh, and eighth cervical and the first dorsal. The animal recovered perfectly from the operation. The cord was not injured in any way. The result was anæsthesia of the left upper extremity. The animal was killed on the twenty-eighth day. The appearances in the cord in section at different levels are shown in Fig. 12.

At the level of the first dorsal (Fig. 12, D 1), there is only a slip of degeneration in the postero-external column, close by the posterior horn. At the next root above (Fig. 12 C VIII), there is extensive degeneration of the posterior region, with the exception of a small wedge at the posterior part of the posterior septum, exactly similar to that already described in monkeys 2 and 4 (Fig. 12, p. v). But what is very noteworthy, is the fact that there is complete and absolute degeneration of the direct cerebellar tract, not the whole of it, but that part lying next the posterior horn; in other words, that part of it which consists in this region of large fibres only. This is continued up the whole of the cervical region to the medulla in the restiform body, and I shall refer again to it in that connection. From this experiment we may say then that the fibres of the posterior roots of the cervical region, and probably of the upper dorsal region, enter largely into the formation of the direct cerebellar tract. In speaking of monkeys 2 and 4, posterior root sections of the lower cord, I emphasised the fact that the direct cerebellar tract was not affected. So that we have again evidence of the difference between the direct cerebellar tract in the upper cord, as compared with the same in the lower cord.

As these observations are important, and rather subversive of hitherto accepted ideas, and as it might be said that some acci-

dental lesion of the tract was caused in cutting the posterior roots, Mr. Horsley was so good as to do two more operations for me as control experiments. I have not had time to cut sections of the cords, but the lesions are quite obvious to the naked eye after hardening. The first of these two was monkey 10, in which there was section of the left posterior roots of the second, third, and fourth dorsal. The second was monkey 11, in which there was division of the left posterior roots of the fifth, sixth, seventh, and eighth cervical and first and second dorsal. In both these the direct cerebellar tract is obviously degenerated, as well as the postero-external and median columns. In Fig. 12 there will be seen a small strip of undegenerated fibres in the middle of the posterior median degeneration. This does not exist in degeneration of the posterior region after transverse lesions of the cord; it is probably, therefore, of ascending commissural fibres.

Fig. 12.—Section of posterior roots of sixth, seventh, eighth cervical, and first dorsal on the left side (monkey 3); d. c. t. (direct cerebellar tract), p. m. (posterior median), p. v. (posterior tract of visceral fine fibres—unaffected); $\times 4$ diam.

Now, how can these results be reconciled with the other facts concerning the tract? As far as the posterior roots are concerned, we can say with confidence that they do not enter in the direct cerebellar tract in the lower dorsal regions, and that they do so largely in the cervical. We can also say with certainty that the direct cerebellar tract is not degenerated after transverse lesions below the tenth or eleventh dorsal.

But in the lower dorsal there are vast numbers of fine fibres in the position of this tract. These fibres cannot be ascending ones, or they would of course degenerate upwards. It must be remembered that at about the seventh or eighth dorsal the fibres of the crossed pyramidal tract come to the surface, and take the position of the direct cerebellar tract. Now the crossed pyramidal tract contains vast numbers of small fibres, probably all descending; therefore it is highly probable that the great number of fine fibres in the peripheral part of the lateral column in the lower dorsal region are really descending fibres. It is also extremely likely that these descending fine fibres enter into communication with ganglion cells in the grey matter, probably with the cells of the posterior vesicular column, and that these fibres are those which so many observers have seen crossing the lateral column. In the monkey the posterior vesicular column has its greatest development at about the level of the last two dorsal roots (Mott), and, therefore, if it supplied the ascending fibres of the direct cerebellar tract, we should expect extensive degeneration of that tract from transverse lesions at those levels, but I cannot find record of such cases.

But there can be little doubt that many of the small fibres in connection with the posterior vesicular column do ascend the cord, and there are at least two paths by which they may do so. One of these paths is the posterior median column, which in

the monkey, and probably in man, has what appears to be a special area set apart for that purpose. I shall refer to that shortly. The second path by which these fibres may ascend is the antero-lateral ascending tract, to which I propose now to devote some attention.

Antero-lateral Tract.—The first to describe this tract was Dr. Gowers⁶ in 1880, but after he had described it, it could be seen to have been figured by many observers,⁷ but apparently by all to have been considered as merely the anterior termination of the direct cerebellar tract, a conception which is still held by some. This tract lies in the anterior part of the lateral column in continuity in many cases with the direct cerebellar tract behind and close to the anterior root-zone in front. It is not a thin strip like the direct cerebellar tract, but a wedge-shaped area with its base at the periphery of the section and its apex towards the grey matter, and sometimes bent posteriorly so as to insinuate itself between the crossed pyramidal and the direct cerebellar tracts. It occupies an area of the cord called by Flechsig the "mixed zone." Now in every transverse lesion of the cord degenerated fibres can be found in the position of this tract.

CASE II, in which the lesion was lower down, shows it particularly well. It will be remembered that in this case the cerebellar tract, though at first degenerated, became very insignificant by about the third cervical, and might be said to have disappeared at the second cervical, but the antero-lateral is at this level extremely well marked and extensive. [The figures illustrating this case will be found in the *St. Bartholomew's Hospital Reports*, vol. xxiii, 1887, p. 141.]

If the lesion be high up in the cord, as in Case v, the distinction between the two tracts is never so well marked as in the lower lesions. This will account for the confusion between the two; but if the lesion be very low down in the cord below the tenth dorsal, we still find the tract degenerates. This is below the point at which the direct cerebellar tract-degeneration begins. This was the condition, as before mentioned, in Dr. Gowers's case. The crush was at about the eleventh dorsal; the posterior median column and the antero-lateral only were degenerated, not the direct cerebellar tract.

Schultze⁸ gives a case of crushing of the lumbar region following fracture of the first lumbar vertebra. There was extensive degeneration of the posterior column and the antero-lateral, but no affection of the direct cerebellar tract. If any further proof of its existence as a tract distinct from the direct cerebellar tract be required, it may be said that Bechterew⁹ has described it developing at a period distinct from other parts. Bechterew was apparently unaware of Dr. Gowers's observation.

Origin of Antero-lateral Tract Fibres.—These cases seem to show that the antero-lateral tract has its origin in the cord low down. It obviously derives none of its fibres from the posterior roots, for in none of my posterior-root sections can any degeneration be found, and the same may be said of Singer's.

If we examine the antero-lateral region in any part of the cord, we find that it contains many fine fibres, resembling in this respect the crossed pyramidal tract and posterior median column. In the cervical region it contains still many, but not so many as in the lower parts of the cord. This may be because the cervical cord has no true posterior vesicular column. But the antero-lateral tract in any part of the cervical region contrasts strongly in this particular with the direct cerebellar tract in the same region. I therefore suggest that the antero-lateral fibres arise solely from the grey matter; that its fine fibres, which are very numerous in the lower cord, are centripetal from the posterior vesicular column; and that the large fibres are in connection with one or more of the groups in the anterior horns. Both these suggestions are hypothetical, however, and are arrived at by a process of exclusion rather than by any positive evidence.

Drs. Hadden and Sherrington¹⁰ contribute an exceedingly interesting observation in this connection. The case was one of locomotor ataxy, in which was found sclerosis of the antero-lateral and posterior regions; the area of fine fibres in and about the posterior horn (Lissauer's tract, so-called) was profoundly degenerated; so were the fine fibres of the posterior vesicular column; but, though there is no obvious degeneration of the

ganglion cells of the posterior vesicular column, the larger variety of them seem to be fewer than normal. The degenerated fibres in the lateral column are diffused at first, that is, about the sixth dorsal; but in the cervical region they are concentrated into the antero-lateral, and can be traced up into the medulla. This case seems to me to confirm the idea that the antero-lateral tract fibres are largely derived from the posterior vesicular column. It is possible that the primary lesion may be situated in the fine fibres constituting the so-called Lissauer's tract, and that there may be a degeneration of the posterior vesicular column, leading to corresponding degeneration of the antero-lateral tract, which I have shown probably receives many of its fibres from the posterior vesicular column.

One must, however, I think, be careful not to reason too closely from observation on system lesions. It does not seem to me to meet the case to call this tract a part of the direct cerebellar tract. It contains quite a different set of fibres. The true direct cerebellar tract consists of large fibres, the antero-lateral principally of small. The direct cerebellar tract derives its fibres from the posterior roots, the antero-lateral column from the grey matter of the cord—or, at any rate, not from the posterior roots. A transverse lesion of the cord high up—say lower cervical—will show degeneration of both antero-lateral and direct cerebellar tracts; but there will be a joining of the two areas, with the result of a strip of degeneration occupying the whole arc of the periphery of the lateral region, and perhaps also, as Dr. Gowers has shown, a continuation of the strip round the anterior root-zone to the anterior column. The farther down the cord the lesion is, the less the cerebellar tract element will be, and the more distinct will be the severance between antero-lateral and direct cerebellar tract, till at last a point is reached below the ninth or tenth dorsal, at which the direct cerebellar tract is not degenerated at all; but the fibres in its position are all descending fibres from the crossed pyramidal tract, and the antero-lateral is affected only.

The above statement seems to me to offer the only explanation which will meet all the facts. Why the upper part of the cord should show such an important difference in its anatomical arrangement from the lower I can at present see no reason, developmental or other.

Destination of Direct Cerebellar Tract.—A point of extreme interest is the termination of the fibres of these two tracts. First, as to the direct cerebellar tract alone, this may be seen very well in the medulla of monkey 3 (Fig. 13). It maintains its position

Fig. 13.—Section of posterior roots of sixth, seventh, eighth cervical, and first dorsal on the left side (monkey 3); medulla (see Fig. 12); d. c. t. (direct cerebellar tract), p. m. (posterior median column), s. g. substantia gelatinosa, v. a. (ascending root of fifth nerve); $\times 2$ diam.

⁶ Gowers, *op. cit.*

⁷ Bastian, *Med. Chi. Trans.*, 1867, p. 499; Westphal, *Arch. f. Psych.*, 1879, p. 413; 1886, p. 788.

⁸ Schultze, *op. cit.*, p. 363.

⁹ Bechterew, *Neurol. Centralbl.*, 1885, p. 155.

¹⁰ Hadden and Sherrington, "Path. Anatomy of a Case of Locomotor Ataxy," *Brain*, 1888, p. 325.

close to and in front of the posterior horn, while the horn becomes enlarged and rounded into the so-called tubercle of Rolando at the level of the first cervical pair. Very soon, however, the tubercle leaves the edge of the section, and assumes the crescent shape of the substantia gelatinosa. Between it and the edge of the section now appears a bundle of fibres, which is the ascending root of the fifth. The direct cerebellar tract still keeps its position, and is then in front of the ascending root of the fifth nerve (Fig. 13, section 5). A little higher, at the level of the upper decussation, the ascending root of the fifth can be seen to be sending fibres past the substantia gelatinosa between it and the direct cerebellar tract (Fig. 13, section 4). Higher still, the direct cerebellar tract is found to be passing externally to the ascending root of the fifth, so that at one point the direct cerebellar tract and the ascending root of the fifth are both external to the substantia gelatinosa (Fig. 13, section 3). Finally, the direct cerebellar tract and the ascending root of the fifth change places, that is, the direct cerebellar tract is found posterior to the ascending root of the fifth, and even posterior to the substantia gelatinosa. At this point the direct cerebellar tract, however much it may be degenerated, receives a large accession of normal fibres, in fact, is now in the restiform body (Fig. 13, section 2).

I have been unable in my sections to trace the degeneration beyond the level of the origin of the eighth nerve, where it lies between the roots of that nerve. Here the fibres begin to take an oblique or horizontal direction to pass to their destination in the cerebellum, and are, therefore, very difficult to follow. Türk followed the tract as far as this, so also have Singer and Westphal. Flechsig believes that the fibres eventually reach the cortex of the cerebellum in the region of the inferior vermiciform process.

Von Monakow¹¹ did a semisection of the cord below the decussation in a newborn rabbit. After six months he found total degeneration of the direct cerebellar tract and part of the corpus restiforme, atrophy of the auditory nucleus, and also of the cortex of the superior vermiciform process of the cerebellum on the same side.

I am much indebted to the important paper on ascending secondary degeneration by Loewenthal,¹² and for further bibliographical information I must refer to his paper. Loewenthal's experiments were on two dogs, in one of which the cord was cut between the first and second cervical roots, and in the other between the fifth and sixth cervical. The direct cerebellar tract he traces to the dentate nucleus in the cerebellum, and supposes that its further course is to the superior vermiciform process. I shall refer to the rest of his paper later on.

The true direct cerebellar tract then passes entirely into the restiform body to the cerebellum. I believe that it is only after lesion of the posterior roots of the upper cord that a simple uncomplicated degeneration of the direct cerebellar tract can be produced. In all lesions of the cord itself in which this tract is degenerated there is a large admixture of the antero-lateral element, which has no direct connection with the posterior root fibres.

Destination of the Antero-lateral Tract.—I will now trace the antero-lateral tract to the medulla. I have no case of simple degeneration of this tract only, except Case II, and the medulla unfortunately is wanting, except one section that I have, in which the appearances are quite unreliable. I am reduced, then, to those cases in which both tracts are affected, such as in monkey 7, Fig. 14, and Case v, Fig. 9. At the level of the first cervical (Fig. 8, C r, Lecture II) the two tracts, antero-lateral and direct cerebellar, are distinct and separated from each other. As they pass upwards, however, they approach each other, and at the level of the commencement of the olive they appear as one long tract (Fig. 14, section 7) lying along the lateral periphery of the section. A little higher (Fig. 14, section 6) this combined degeneration is nearly divided into two by the appearance of normal fibres, and also by many horizontal arciform fibres. This is the point at which, as before described, the direct cerebellar tract passes behind the ascending root of the fifth. At the next section (Fig. 14, section 5) the severance between the two tracts is quite unmistakable. The direct cerebellar tract is now in the restiform body. The ascending root of the fifth has passed in front, and has gained

the edge of the section, and thus the antero-lateral tract has taken up its position in front of this in the angle formed by the projecting olive with the lateral edge of the section, close in front of the point of exit of the vagus nerve. It maintains this position, as far as I can trace it, that is in this series of sections, to the level of the points of exit of the seventh and sixth nerves (Fig. 14, section 1). Here there are very few degenerated fibres.

Fig. 14.—Semisection of cord between seventh and eighth cervical (monkey 7); medulla (see Fig. 8); d. c. t. (direct cerebellar tract), a. t. (antero-lateral tract), c. r. (corpus restiforme), s. g. (substantia gelatinosa), o. i. (lower olive), o. s. (upper olive), v. a. (ascending root of fifth nerve); $\times 2$ diam.

This observation on monkey 7 is the most complete that I have to offer—and I admit that it leaves much to be desired—in further elucidation of this interesting question. I feel perfectly secure in reasoning from the monkey's medulla to that of man, because of the extremely close similarity in anatomical respects between the two.

I have sections and diagrams from my Case v, Fig. 9, which I referred to in tracing up the posterior degeneration. It will be remembered that the division between the antero-lateral and the direct cerebellar tract was never very complete in the cervical re-

¹¹ Von Monakow, "Zur Kenntniss des Äusseren Acusticuskerne und des Corp. Restiforme," *Neurol. Centralbl.*, 1882, p. 481.

¹² Loewenthal, "Dégénération Secondaires Ascendantes," etc., *Rev. de Méd. d. la Suisse Romande*, 1885, p. 511.

gion. In the lower medulla, as in the monkey last described, there is one degeneration only (Fig. 9, sections 4 to 7, d. a.); a large

Fig. 9.—Medulla of Case v (see Fig. 7); a. t. (antero-lateral tract), d. c. t. (direct cerebellar), d. a. (direct cerebellar and antero-lateral tracts combined); p. m. (posterior median), c. r. (corpus restiforme); $\times 2$ diam.

comma-shaped area, with its head in front of the substantia gelatinosa, and its tail passing back outside the ascending root of the fifth (Fig. 9, v. a.). This appearance obtains till we reach a point a little above the commencement of the olive (Fig. 9, section 3). Here, on the right side, the direct cerebellar tract has taken its place in the corpus restiforme (c. r.), and anteriorly not far below the olive lies a patch of degenerated fibres, not compact like the direct cerebellar tract, but more diffuse. This is faintly represented in the two succeeding sections (Fig. 9, sections 1 and 2), the highest of which is through about the middle of the olive. Unfortunately, I had no more of the medulla for examination. The ultimate destination of the tract is conjectural. It certainly appears to have some relations with the nucleus lateralis. In the lower part of the medulla, at the commencement of the olive, there is a collection of ganglion cells (Fig. 14, section 7, a. h.), which is the remnant of the anterior horn of the cord. The cells are of the usual large multipolar type of the anterior horn. A little posterior to it can be seen a small group of cells of the small bipolar type. This is the nucleus lateralis, and is the upward continuation of the lateral horn of the cervical cord,¹⁴ also called the "visceral horn." Higher up, the large cells of the old anterior horn become very few, while those forming the nucleus lateralis become more

numerous. Eventually, just above the olive, the small bipolar cells in their turn can no longer be seen, but in their place a compact nucleus of large cells makes its appearance, the nucleus of the seventh nerve. It seems, then, to me scarcely correct to say that the seventh nerve arises from the upward continuation of the lateral horn. It arises from a mass of large multipolar cells, as one might expect an essentially motor nerve to do, these large cells having replaced the small cells of the nucleus lateralis. It is at this point that in monkey 7 (Fig. 14, section 5) the last trace of degeneration can be seen.

I must here again refer to Bechterew's work on the development of this tract. He distinctly states that the developing bundle ends in the nucleus lateralis. This countenances the supposition that the tract has some relations with the nucleus lateralis. I have said above, in discussing the minute anatomy of the tract, that it consists, unlike the direct cerebellar tracts of fine visceral fibres as well as large. I suggest therefore that the fine fibres really end in the nucleus lateralis.¹⁵ I can form no conclusions from my own observations as to the further course of the fibres, but the work of Loewenthal,¹⁶ already referred to, may throw some light on the question.

Loewenthal performed a transverse section of the cord in the cervical region. The result was degeneration of what he called the direct cerebellar tract, but a glance at his figures shows that he had produced a combined degeneration similar to that in Fig. 7, C II (right side), in other words he had degeneration of the direct cerebellar tract, and also degeneration of the antero-lateral tract, which was not at that time generally recognised as a distinct tract. In the medulla he describes the true direct cerebellar tract passing into the restiform body, and, as he says, a part of it taking up a position in the medulla anterior to this; in fact, exactly the position I have described above in monkey 7. He calls these fibres the "ventral cerebellar fibres." The interest of his observation lies in the fact that he traces these "ventral fibres," which I believe to be the antero-lateral tract, through the pons into the superior peduncle of the cerebellum. It is possible then that the fine fibres of the tract end in the nucleus lateralis with its small ganglion cells, and that the large fibres take a further course, and eventually gain the cerebellum by way of the superior peduncle.

As to the function of these two tracts I have little to say. The direct cerebellar must, I think, conduct some form of sensory impression from the upper part of the body, the antero-lateral fibres from the lower.

The direct cerebellar fibres admittedly pass into the cerebellum. The antero-lateral large fibres possibly also pass to the same, by way of the superior peduncle.

Disease of the cerebellum causes marked loss of co-ordination of muscular movements of both upper and lower limbs, besides other obscure symptoms. May then the large fibres of the antero-lateral and the direct cerebellar tract be for the conduction of kinesthetic impressions?

Dr. Gowers¹⁶ places the path of conduction of impressions of pain in the antero-lateral region. This he bases on a case of gunshot injury of the cervical region, which, however, produced such extensive lesion of the grey matter as well as the white in one-half of the cord, that the case might almost be regarded as a semi-section. Bechterew¹⁷ also supposes that the antero-lateral region conducts pain-sense, because he says that analgesia follows transverse section of the anterior half of the cord, but not after the same lesion in the posterior half.

In neither of these observations can we eliminate the grey matter; any crossing that takes place must take place there. The direct cerebellar tract does not appear to cross at all in the cord. The antero-lateral does not cross after leaving the cells of the grey matter, but of course the impressions it conducts may have crossed in the grey matter.

More precise experiments on animals are needed before any definite conclusions can be arrived at.

Visceral Nerve Fibres.—I have many times incidentally drawn attention to the fibres in the cord, which are medullated, but of the finest

¹⁴ Von Monakow, *Arch. f. Psych.*, 1883, p. 1, describes and figures the results of a half section of the cord just below the decussation in a new-born rabbit. He found almost complete atrophy of the cells of the nucleus lateralis. This result seems to confirm the view above suggested, that certain ascending fibres enter into direct connection with the nucleus lateralis.

¹⁵ Loewenthal, *op. cit.*

¹⁶ Gowers: Case of Unilateral Gunshot Injury to the Spinal Cord, *Clin. Soc. Trans.*, vol. xi, 1877.

¹⁷ Bechterew, *op. cit.*

³ Hill, "Plan of Central Nervous System," Graduation Thesis, Cambridge, 1885.

calibre. I propose now to deal with these a little more systematically, both from the standpoint of anatomy and secondary degeneration. These fibres have been recognised for many years, but no real significance seems to have been attached to them till the researches of Onodi, Gaskell, and Lissauer. Of these observers we undoubtedly owe most to Dr. Gaskell.¹⁸ His work on the subject is of the profoundest anatomical and physiological interest, and marks, to my mind, a most important departure in neurology. According to his researches, the following conclusions may be arrived at.

Every typical spinal nerve consists of three branches—dorsal, ventral, and visceral. The visceral branch is the white ramus communicans, and consists almost entirely of fine medullated fibres. The grey ramus contains nothing but non-medullated fibres, and is distributed as a peripheral branch to the blood-vessels of the cord and membranes.

The anterior and posterior roots of such a typical spinal nerve also contain large numbers of fine medullated nerve-fibres. Those in the anterior root are efferent, and pass out to make up the white ramus aforesaid; those in the posterior root are, presumably, afferent. The visceral branch, or white ramus communicans, passes to its destination in the vessels, glands, or viscera, but is sooner or later brought into communication with a ganglion belonging to what is known as the sympathetic system; its fibres either pass on through the ganglion to other ganglia of the same kind, or else enter into direct communication with the cells of the ganglion. In the latter case the fibres lose their medulla and continue to their final distribution in the vessels or viscera as non-medullated fibres; so that the conception of the nerves and roots of a typical spinal segment would be (1) a posterior root with a ganglion having a fixed position, the root being made up of large fibres (somatic) and small fibres (splanchnic) afferent in direction; (2) an anterior root, consisting of large and small fibres not in connection with any ganglion, and a number of small fibres which are in connection with ganglia, but the ganglia are remote and of no fixed position.

This typical arrangement of large and small fibres only exists obviously in the cord from the second dorsal to the second lumbar (in the dog). At first sight it would seem that the cervical and lower cord were without such visceral nerves. In the cervical region, however, the upper roots of the spinal accessory and lower roots of the vagus contain all the fine visceral fibres arising from that part of the cord. They pass to the ganglion of the vagus trunk, where many of them lose their medulla.

Again, in the lower sacral region there is another "outflow" of visceral nerves, forming the so-called "nervi erigentes." So that we have three principal "outflows" of fine visceral nerve fibres:—I. A cervico-cranial outflow in connection with the vagus and spinal accessory nerves (cervical splanchnics). II. A thoracic outflow (abdominal splanchnics). III. A sacral outflow (pelvic splanchnics).

Visceral Nerve Fibres in the Cord.—So far, we have considered the relation of the fine visceral nerve fibres with the spinal roots and nerves. We have now to examine their course and connection in the cord itself. My remarks on this subject again are based on examination of the monkey's cord, because as these fibres are very fine high powers are required, and it is quite essential that decomposition should not have even begun. The fine fibres of the cord may be said to be disposed in two ways: in the ordinary large fibre tracts, or in bundles by themselves practically unmixed with large fibres. It is highly probable, speaking generally, that the fine fibres included under the first head course in the same direction as that of the tract in which they are situated. It is certain that, in cases of complete degeneration of a tract after section of the cord, the fine fibres have disappeared with the large. This disappearance can only be accounted for by the degeneration of the fibres themselves, unless we suppose with Schiefferdecker that the degeneration can spread laterally beyond the affected fibres. Fine fibres degenerate in exactly the same manner as large, and exhibit the same decomposition changes.

Efferent Visceral Nerve Fibres.—If we examine the anterior pyramids of the medulla, we are at once struck by the vast numbers of fine fibres they contain; this may be said also of the pyramidal tracts above in the pons. The crossed pyramidal tract all the way down the cord is closely packed with these fibres; so closely that this tract, in normal monkeys' cords, takes ordinary stains so deeply as to be quite apparent to the naked eye. When the crossed pyramidal tract is cut across, as in monkey 7 (Fig. 8)

we find the degeneration of the tract below the lesion is very complete; very few, if any, normal fine fibres can be seen in it. This condition obtains in the tract to its termination in the sacral region. We may say, then, I think, that the crossed pyramidal tract, besides containing descending large and medium-sized fibres, contains also descending or efferent fine fibres. The anterior columns also contain large numbers of fine fibres, but the bulk of them lie close to the anterior horns in the anterior radicular zone. I cannot find that these degenerate downwards, and therefore probably they are commissural or on their way out into the anterior roots.

As is the case with the large fibres of the crossed pyramidal tract, so the small fibres of this tract run from the higher centres in the medulla or brain to lower centres in the cord, and no further. As Dr. Gaskell has pointed out, one of the most important of these lower centres is the posterior vesicular column of Clarke. The principal, if not the only, efferent path of communication between the brain and the vessels and viscera is the crossed pyramidal tract. The fibres of the crossed pyramidal tract have been long known by physiologists to influence the vasomotor system.

Afferent Visceral Nerve Fibres.—The paths by which these fibres ascend to the higher centres are also well defined. One important ascending tract, at any rate, we may exclude, as I have shown, from having any share in the transmission of the visceral fibres—namely, the direct cerebellar tract. Any small fibres that this tract may contain are derived from the crossed pyramidal tract, and therefore not ascending at all. The antero-lateral tract is not so exclusively composed of large fibres, and contains a large number of small fibres. In my monkey 7 this tract is largely degenerated above the lesion; the degeneration affects large and small fibres. Moreover, the degeneration is also, according to my other observations, of a diffuse character; and even when most affected, the tract always seems to present many normal fibres mixed up with the degenerated ones. Then again, for some way below the lesion, we find degenerated descending fibres in the antero-lateral tract; therefore, the name "mixed zone," originally given by Flechsig to this region, is still applicable. However, it is probable that this tract is one of the paths by which the visceral fibres reach the higher centres, and I have suggested the nucleus lateralis as the highest point of their destination. The whole of the posterior region is thickly supplied with fine fibres. No doubt large numbers of these are on their way to the centres in the grey matter; they are found in the posterior roots of the lumbar and dorsal regions, but very few in the lower and middle cervical. In fact their presence in the posterior roots is governed by the presence of the posterior vesicular column. But there is a part of the posterior region which is specially devoted to conducting the visceral fibres.

In 1886 Lissauer¹⁹ drew special attention to the anatomy of the posterior horn. Strictly speaking, the posterior horn never reaches the edge of the section, but ends at varying distances from it according to the level of the section in what appears to be a rounded tubercle. This is the substantia gelatinosa Rolandi, and is probably not nervous at all. What appears as the tip of the horn is in reality some of the posterior root-fibres passing to pierce the substantia gelatinosa. The zone which lies between the substantia gelatinosa and the edge of the section is called by Lissauer the "*Randzone*," or border zone. This zone in the lumbar and sacral region is broad because the substantia gelatinosa is broad, and short because the substantia gelatinosa comes close to the surface. In the lower dorsal region the substantia gelatinosa is a long way from the surface, and, therefore, the border zone is long and narrow, lying on each side of the fibres passing to enter the horn. Now this zone, after staining by Weigert hæmatoxylin, has a fine stippled appearance, which is due to the great number of fine fibres seen in transverse section. This zone in the upper dorsal region recedes from the surface more and more till it becomes, as it were, applied in the substantia gelatinosa. It is small in the cervical region, but in the vicinity of the entering fibres of the posterior roots there are always grouped a number of small fibres, and, therefore, this "border zone" cannot be said to be absent anywhere in the cord.

The significance is that it marks the entry of the fine fibres from the posterior roots. It is very consistently sclerosed, as Lissauer has pointed out, in tabes, a circumstance which will, as our knowledge grows, no doubt account for many of the obscure

¹⁸ Gaskell, "Visceral Nerves," *Journal of Phys.*, vol. vii, 1886; also, Marshall Hall Oration, *Med.-Chi. Trans.*, 1888, p. 363.

¹⁹ Lissauer: Beitrag zum Faserlauf des Hinterhorns, etc., *Arch. f. Psych.*, 1886, p. 377.

visceral symptoms of that disease. It is, of course, degenerated secondarily to section or disease of posterior roots of that side, but the degeneration rarely extends far up, and therefore it is most likely that its fibres pass sooner or later into the posterior vesicular column or into the posterior median. The border zone then bears the same relation to the fine fibres as the posterolateral does to the large. Bechterew,²⁰ in 1885, had anticipated Lissauer somewhat by showing that this zone develops in the embryo at a time distinct from the rest of the posterior region.²¹

But it is probable that many visceral fibres, entering by the posterior roots, ascend the cord without communicating with the grey matter at all. The path taken by them is the posterior median column. In man this column is crowded with fine fibres. In the monkey, though the whole of the posterior median column is packed closely with them, there is a small part of the column set aside apparently for the special path of the fine fibres. This appears as a small wedge at the posterior part of the posterior septum (see Figs. 10, 11, and 12, p. v.); in it there are very few, if any, large fibres. This little tract runs right up to the medulla, and perhaps ends in the grey matter of the floor of the fourth ventricle.

We have now a complete visceral system in the cord on the same plan as the motor and sensory system of large fibres. The study of the visceral system of nerves is yet in its infancy, and its bearing upon clinical medicine is practically a new field. Is it not possible that we may by it throw some light on the pathogeny of such obscure diseases as diabetes, Addison's and Graves's disease, and perhaps even myxœdema?

My task, as far as these lectures are concerned, is ended, and yet it can scarcely be said to have begun. I have adhered strictly to my text, perhaps too strictly. I am quite aware that I have left untouched the important field of the physiology or functions of the various bundles of fibres in the cord. To deal with this subject at all satisfactorily on clinical grounds requires an experience to which I can lay no claim. To study it from the standpoint of physiological experiment would be practically impossible in the time allowed for the preparation of these lectures. It has taken fifty-three years to arrive at our present state of knowledge concerning the anatomy only of the spinal cord, from the point of view of degenerations; and I have spoken to little purpose if I have not made it evident that there is yet much to learn. If this be true of the anatomy, it is still more so of the physiology of the cord. If our art be so long that one life is too short to compass it, how much longer, then, must it be before we can pretend to understand the secrets locked up in a structure, the highest and most subtle result of evolution that Nature can show?

ERASMUS WILSON LECTURES

ON THE PATHOLOGY OF

GLAUCOMA.

Delivered at the Royal College of Surgeons of England, March, 1889

By PRIESTLEY SMITH, M.R.C.S.,

Ophthalmic Surgeon to the Queen's Hospital, Birmingham.

LECTURE III.

WE call a glaucoma primary when we are unable to point to a previous disease of the eye as its cause. The obscurity of its origin distinguishes the primary from the various forms of secondary glaucoma which we have already considered. It is important to observe, however, that, apart from their initial causes, primary and secondary glaucoma are, to a large extent, one and the same morbid process. Pressure, the essential factor, is common to both. The other leading symptoms of primary glaucoma—the progressive loss of vision, the contraction of the field, the cupping of the disc and, in the more acute forms, the pain, the injection, and the rapid abolition of sight—these are all to be found in one or other form of secondary glaucoma also. They are absent only in so far as they are hidden, or modified, or forestalled by the pre-existing disease of the eye. The special interest which belongs to the pathology of primary glaucoma lies at present, I think, not so much in the evil

consequences of high pressure—these are now fairly well understood—as in the mysterious nature of the causes which can give rise to a formidable disease to-morrow, in an eye which looks perfectly healthy to-day.

Clinical observation alone, however acute, fails to explain the malady. I will, therefore, in the first place, ask your attention to certain conditions which are found in eyes which have been blinded by primary glaucoma, and excised. Many minute descriptions of such specimens have been published, notably by Brailey in this country, by Knies, Weber, and Birnbacher and Czermak in Germany. I have myself examined about twenty-five specimens of primary glaucoma, and have placed many of them here for your inspection.

One word as to the method of examination. My own specimens were hardened gradually in Müller's fluid, and divided in the frozen state. I believe that it is not possible to open an eye in any other way without disturbing the relations of its internal parts; and even this method does not always enable us to see the parts exactly in the positions which they have occupied in the living eye. If the lens is elastic, it will become more globular when the tension of the suspensory ligament is relaxed; if it have been pushed forward by an excess of pressure in the vitreous chamber, it will tend to return to its normal position when the pressure falls after the removal of the eye. It is important to bear these points in mind in considering the changes which I have now to describe.

The filtration angle is closed, or at least compressed; I have seen no case in which it was normally patent. If the glaucoma have been of short duration, the iris-base may be merely pressed against the cornea, and may separate from it in the divided eye (see Fig. 27)¹. In older cases it is firmly adherent to it, and often much

Fig. 27.—Primary glaucoma—recent. The adhesion seems to form most rapidly

Fig. 28.—Primary glaucoma of long standing.

when there is much vascular disturbance; in the very chronic non-irritative form of glaucoma it occurs late, and sometimes not at all; but even in these cases there is always, so far as my observation goes, a well-marked compression of the filtration angle. Sometimes the iris-base adheres to the processes, and is drawn backwards when they retract, so that its adhesion with the cornea is more or less torn through; or, if it is not torn through, the iris-base may be stretched in the direction of its thickness, and present a peculiar bend or notch in its anterior surface just at the limit of the adhesion (Fig. 44).

The ciliary processes are usually altered, both in size and in position. If the glaucoma have been of recent date and congestive type, they are enlarged, their apices extending forwards far beyond the customary limit (Fig. 29).² In such cases they are in close contact anteriorly with the iris, internally with the margin of the lens; or, if no longer in contact, their wedge-like shape shows that

²⁰ Bechterew, *Neurol. Centralbl.*, 1885, p. 369.

²¹ See also Sherrington, *Brain*, vol. ix, p. 342

¹ *Ophth. Rev.*, 1882, p. 80.

² *H. and Ophth. Hosp. Reports*, vol. x, p. 25.