Critical Digests.

ON THE TRACTS OF THE SPINAL CORD AND THEIR DEGENERATIONS.

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INTRODUCTION.

It is my object in this digest to confine myself as strictly as possible within anatomico-histological limits. I propose to review at length the observations of those who, as anatomists or histologists, have investigated, experimentally or otherwise, secondary degenerations and scleroses; to consider the publications of workers on the normal anatomy, on the development, and on diseases of the spinal cord, only in so far as they bear upon the spinal nerve tracts; and in conclusion to briefly refer to the changes which occur in the spinal cord after amputations of extremities.

The importance of the contributions which have been added to our literature on secondary degenerations of the spinal cord during the past decade, and the augmentation of our knowledge accruing therefrom, cannot be over-estimated. A reason for the refreshing zeal and industry displayed by workers on this subject is readily found; its mainspring has undoubtedly been the discovery and elaboration by Marchi of his now famous osmium-bichromate method. In the same way as the introduction of the silver method of Golgi has stimulated the neuro-histologist, so the method of Marchi has given a fresh impetus to the neuropathologist and proved an especial boon to the experimenter on secondary degenerations; by reason of the delicacy of its working even sparsely disseminated degenerated nerve fibres can be traced with perfect ease and accuracy, and thus many breaches left open by the method of Weigert have now been satisfactorily filled.

To suit purposes of convenience, I shall adopt as my scheme in this periscope the arrangement of the various columns or tracts of the spinal cord into the two main physiological groups,

ascending and descending, and I shall discuss the points concerning the development, the origin, course, connections, and termination of each column individually.

The degenerations which result from spinal hemisections, from sections of nerve roots, &c., and from cerebral and cerebellar lesions, will not be dealt with under special headings, but they will be referred to under the particular spinal tracts which they affect.

PYRAMIDAL OR MOTOR TRACTS.

The pyramidal or motor tracts have certainly been more attentively studied of late years by experimental neurologists and neuro-pathologists than any other spinal tract, and consequently there is no other tract concerning the course, the connections, and the functions of which we are more enlightened. Yet, while congratulations are due to the various investigators who have assisted in bringing our knowledge of the tract to this advanced stage, there are, nevertheless, several points, as will be presently indicated, bearing more especially on its connections and its termination, which demand further elucidation and prevent us from declaring that our researches on the subject are yet complete.

Development.—In regard to development, Flechsig's most valuable researches have definitely proved that in the human foetus there is no trace of myelinisation of the fibres of the pyramidal tract until the end of the normal period of gestation, and yet certain other white columns receive their medullary investment, and can be readily recognised on that account as early as the fifth month of intra-uterine life. Then Bechterew has shown, that in those animals which are endowed at birth with the power of locomotion, the pyramidal tracts are almost completely developed before the termination of the period of gestation. Bechterew has also demonstrated that in animals possessed of coarse movements only, such as the whale, the pyramidal tracts never attain a high stage of development; and it may be accepted as a general rule of comparative anatomy that the degree of development of these tracts is proportional to the multiplicity, complexity, and delicacy of the movements of the animal.

In a research having as its object the determination of the period which elapses before secondary degeneration becomes evident in the various tracts of the spinal cord after an experimental lesion, Schäfer arrived at the conclusion that an analogy exists between the time of onset of secondary degeneration and the period of development of the medullated sheath of the fibres composing these and other tracts. Schäfer employed the cat in

his researches, and after a hemisection of the cord found that degeneration commenced in the column of Goll on the fourth day after the operation, it appeared in the dorso-lateral cerebellar tract on the sixth day, but it was not until the fourteenth day that it became evident in the one of tardiest development, viz., the pyramidal tract. Worotynski has written in confirmation of Schäfer's observations.

Volume.—Recent work confirms the variability in relative volume and representation of the anterior and lateral pyramidal tracts one to another in the spinal cord. According to Flechsig's original doctrine, their relative volume varies with the extent and completeness of the crossing at the point of decussation in the medulla oblongata. In 75 per cent. of cases this decussation is relatively equalised, and well developed anterior and lateral pyramids, which we may regard as normal, are to be found. In the remaining 25 per cent. the crossing is either unequal, incomplete, or excessive; if the decussation be unequal, that is to say, if there be more fibres crossing from one side than from the other, then in that side from which the major number of fibres decussate the pyramidal tracts, both anterior and lateral, will be poorly represented; if, on the other hand, the decussation be incomplete, then the relative size of the direct pyramidal tracts to the lateral ones will be increased above normal; and if, finally, the decussation be complete, then the condition is arrived at which Boyce, Sherrington, Singer, and others have proved to exist in some of the lower animals, viz., the cat, dog, and monkey, in which there is an almost complete absence of the direct pyramidal tracts and relatively large sized lateral tracts.

Length.—In the same way as the volume of these tracts is for the above-mentioned reasons exceedingly variable, so their length is never exactly equal in different individuals, a fact which accounts for a number of discrepancies which appear on reading the observations of various writers. Thus, whereas Bouchard told us that the direct pyramidal tract terminated in and did not descend lower than the mid-dorsal region, Tooth has traced it to the second lumbar segment, and the most recent observers of all, Déjérine and Thomas, assisted by the method of Marchi, have now followed it down to the level of the sixth sacral pair of nerve roots. Then in regard to the lateral pyramidal tract, Loewenthal and Vulpian fixed its termination at a point opposite the origin of the second lumbar pair of nerve roots, Tooth saw it opposite the fourth lumbar roots, and Déjérine and Thomas now find that it actually ends in the conus medullaris, but ceases to exist as a compact bundle at the level of the fourth sacral roots.

Origin and Course.—That the trophic cells for the fibres of the pyramidal tracts are the large pyramidal or multipolar cells situated in the motor region of the cerebral cortex, *i.e.*, the ascending frontal and ascending parietal convolutions and the posterior parts of the first and second frontal gyri, is almost unanimously agreed. But a destructive lesion involving these parts gives rise to secondary degeneration, not only of the recognised motor tracts, but also of other systems of fibres; and though it is not definitely known that the performance of motor acts is dependent upon these other systems, yet it is more than probable that there is some relation, and since the view that a pure motor act is considerably more complex than it was originally supposed to be is every day gaining more supporters, it is possible that these systems aid in the production of that complexity, and it will, therefore, be necessary to mention them.

In the first place Monakow, Redlich and others, after destruction of the motor area of the cat, found marked evidence of degeneration in various parts of the thalamus opticus; the same observers, and also Meynert, likewise found degeneration in the substantia nigra of Sœmmering. Redlich in the human being, as well as in lower animals, has constantly found degeneration of fibres leading to cells in the nuclear matter of the pons, and he suggests that these are collaterals of the pyramidal fibres, and that they are connected by means of a second neuron¹ with the opposite cerebellar hemisphere. Also there have been found degenerated certain fibres of the lemniscus (*viz.*, the lateral pontine bundle of Schlesinger) and internal and external arcuate fibres; and, lastly, fibres have been followed from the pyramidal tract to certain cranial nerve nuclei, *viz.*, the facial and hypoglossal (Hoche).

One has only to contrast the small size of the pyramidal tracts as they lie side by side on the ventral aspect of the medulla oblongata, with the size of the tracts in the crus for instance, to be convinced that an appreciable number of fibres must diverge in the manner above indicated, and Starlinger's experiments on the dog seem to prove that these diverging fibres possess a most important bearing on motion, for he found that section of both pyramidal tracts in the medulla oblongata was attended by no lasting interference with movement, whereas the usual paralysis

¹ Throughout this digest the term "neuron" is employed in its broad and more generally accepted sense, *i.e.*, it includes a cell body along with its dendritic processes or neuro-dendrons and its axis-cylinder process or neuraxon. This note is deemed necessary because some apply the term to the axis-cylinder process only.

followed a lesion of the motor area in the same animal. Redlich obtained like results in the cat, and to account for the opposite consequences in these two operations, they conclude that some fibres other than those embodied in the pyramidal tracts in the medulla oblongata must exist as channels for the conduction of motor impulses, and that some of the diverging fibres above-mentioned must form some of these channels. Doubtless fresh researches will shortly shed new light on this point.

Otherwise there is nothing new to remark concerning the disposition of the motor tract in the internal capsule, the pes, the pons, or the medulla oblongata above the decussation. The exact nature of the decussation of the pyramidal fibres at the lower end of the medulla and elsewhere is, however, still a source of fruitful discussion. This portion of the tract has been dealt with at length by Rothmann; and Boyce, Mott, Déjérine and Thomas, Redlich, and others have made incidental references to it in connection with remarks on the occurrence of bilateral degeneration in the spinal cord in consequence of a unilateral cortical lesion, and since these two subjects are inseparable they will be dealt with together at this stage.

(a) *The Pyramidal Decussation*; (b) *Bilateral Spinal Degeneration in consequence of a Unilateral Cerebral Lesion*.—Bilateral degeneration in consequence of a unilateral cerebral lesion was first drawn attention to by Westphal as early as 1875. Pitres worked the matter up very thoroughly some years later, Muratoff and others have obtained the degeneration in dogs, Mott and others have found it in the monkey, and Boyce and others have seen it in the cat. Numerous and intricate theories have been promulgated to explain this bilateral degeneration, and though most of these are happily now of historic import only, yet it will be interesting to give a brief outline of the more important ones.

Firstly, Charcot believed that in addition to the usual decussation in the medulla oblongata there occurred an extra crossing in the anterior commissure of the cord, but the method of Marchi overthrows this view by failing to reveal degeneration in this situation. Then Hallopeau, who received the support of Marie and Pitres, thought that at the decussation in the medulla oblongata the fibres from either side come into such close contact with one another that direct extension of the inflammatory process from the diseased to the normal fibres must occur.

Passing over the work of Franck, Moeli, and Schäfer, we next come to the very thorough experimental investigations of Sherrington, which led him to assume that the degenerated fibres,

which are to be seen descending in the lateral pyramidal tract on the same side as the lesion, are derived from fibres of the opposite lateral tract, which, having already decussated at the usual situation, leave it to recross in the grey matter of the spinal cord and regain the side of the lesion without coming into connection with ganglion cells in the grey matter through which they pass. For these fibres he suggested the name "re-crossed pyramidal fibres." Sherrington's observations received support from Unverricht, Kusick, and Vierhuff; but, on the other hand, Loewenthal, Fürstner, and Knoblauch, who practised like experiments, did not get similar results.

Now it must be mentioned that all these observers worked before the method of Marchi, which is so exquisitely adapted for picking out isolated degenerated fibres, was discovered, and as they could only practise the staining methods of Weigert, &c., much of the value of their researches must be discounted.

Since the introduction of Marchi's method the matter has been taken up, amongst others, by Sandmeyer, Muratoff, Boyce, Mott, Hoche, and Rothmann.

Sandmeyer obtained bilateral degeneration nine days after experimental cortical lesions, but offers no explanation as to its occurrence.

Boyce and Mott in the cat and monkey respectively, Déjérine and Thomas in the human being, Muratoff in the dog and in the human subject as well, endeavour to explain the homo-lateral degeneration by a direct passage at or about the level of the decussation of fibres from one cerebral hemisphere to the lateral pyramidal tract on the same side as the lesion.

Marchi, as a result of experimental investigation, attributes the bilateral degeneration to an extra decussation higher up, viz., in the corpus callosum. This idea is supported by Hamilton, but it has been practically nullified by the work of Muratoff and others.

We lastly come to the observations of Rothmann, who examined the spinal cords of dogs operated on in Munk's laboratory and obtained the bilateral degeneration in every instance. His view as to its production is in a sense a revival of that of Hallopeau above mentioned, viz., that it originates at the pyramidal decussation, and that it is due to compression of the bundles of fibres from the healthy side by the swollen bundles of degenerated fibres which are coming from the side on which the lesion was. He urges in support of this that four weeks after the operation the homo-lateral degeneration is no longer recognisable, and publishes convincing drawings to illustrate his views.

From the foregoing it is painfully obvious that the anatomical disposition of the pyramidal fibres at the decussation is by no means clearly understood, and that the source of the bilateral degeneration is not agreed upon.

Topography and Termination of the Lateral Pyramidal Tract.—In regard to the topographical distribution of the lateral pyramidal tract in the spinal cord there is little new, only the method of Marchi has shown that its limits are not so sharp as was formerly supposed, and that scattered aberrant fibres are to be seen in considerable abundance in the columns situated immediately ventral to the old boundary of the tract. These fibres are especially noticeable in the cervical region.

We still require enlightenment as to how and where the pyramidal fibres terminate in the grey matter. Kölliker, Golgi, Ramon y Cajal, Sherrington, and Lenhossek, mainly aided by the method of staining by metallic impregnation of the myelin, have shown that the pyramidal fibres at intervals in their course along the cord issue numbers of collaterals, and Lenhossek claims that these collaterals are not directly connected, as one would suppose, with the ganglial cells of the anterior cornua, but only indirectly so by the intervention of cells of the posterior cornua to which they course and around which they arboresce. This statement, however, requires confirmation. Then, in regard to the termination of the main trunks of these fibres, physiologically proof is not wanting that they are connected with the multipolar cells of the anterior cornua on the same side, but anatomically that link of the fibre, situated between the lateral column and the anterior cornual cell, has not yet been satisfactorily defined. Experimental workers (Starlinger, Monakow, Rothmann, Redlich) employing the method of Marchi, have been unable to trace degenerated fibres from the lateral column to the anterior cornual cells; but it is possible that these observers examined the cords of their animals too soon after the operation, and that they would have detected degeneration if they had allowed them to live longer; because in the case of the spinal cord of a man examined by the writer, in which there was profound descending degeneration in consequence of an extensive cerebral thrombosis six weeks old, the method of Marchi showed distinct darkening of the myelinic plexus in the anterior cornu on the side of the degenerated lateral pyramid, though a connection between any fibre in the lateral column and any anterior cornual cell in its entirety was not traceable. Of course, the difficulty here is that not only is the course of the fibre apparently tortuous, but also it

more or less entirely sheds its myelinic investment as soon as it enters the grey substance, and therefore cannot be clearly followed by a method which has for its object the display of disintegrating myelin.

Monakow discredits the existence of a direct connection between lateral column fibre and anterior cornual cell, and assumes that between the spino-muscular or anterior cornual cell neuron and the cortico-spinal or pyramidal cell neuron, a third neuron is interposed, composed of a cell after the nature of Golgi's second type, and that this cell is situated in the region of the processus reticularis.

Anterior or Direct Pyramidal Tract.—Turning next to the direct pyramidal tract, it has been proved that this tract practically does not exist in the cat or the dog, and likewise in the monkey there appears to be no adequate homologous representation; also, in the light of recent research, the tract is being divested of much of the importance it originally possessed in the human being, and is considered to be less extensive and less voluminous than Ludwig Türck, its original discoverer, taught us to believe. Türck's description of the tract was founded on observations of the changes in the cord resulting from capsular cerebral lesions, and not from cortical lesions. Now the difference between the degree of degeneration in the anterior pyramidal tract after a cortical lesion contrasted with that after a pontine or a capsular lesion is exceedingly marked. In the case of the latter the degeneration in the antero-internal column is profound and complete, but in a case of destruction of the cortical motor sphere the direct pyramidal tract degeneration is never more than partial, that is to say, the degenerated fibres are disseminated throughout it, and are surrounded by an equal or greater number of healthy fibres. These points of difference are well seen in a number of specimens of sections of cords of human beings prepared by the writer. There is no entirely satisfactory explanation of the difference in degree of the degeneration in the anterior pyramid in these two lesions; it can only be assumed that certain fibres which course down in the antero-internal tracts are not derived from the cerebral cortex, but take their origin from structures in the capsular region. For instance, Boyce's cerebral hemi-extirpation experiments in the cat show that the fibres of the posterior longitudinal bundles descend in the antero-internal tract on the same side as the lesion. I am not aware that these fibres have been traced so far downwards in the human being, but it is possible that they can be, and that the source of these fibres, by

Bechterew supposed to be in the optic thalamus, is destroyed in a capsular lesion, whereas it of course escapes in a cortical one.

The anterior pyramidal fibres, like the crossed ones, issue numbers of collaterals in their downward course, and these collaterals, and likewise the main trunks of the fibres, are believed to pass over in the anterior commissure, and to terminate by arborescing round cells in the opposite anterior cornu.

"Retrograde Degeneration" in the Pyramidal Tract.—The name "retrograde degeneration" has been assigned by Sottas to an ascending change in the pyramidal tracts, which that author observed in four cases of medullary syphilis, in which the lesion was a softening followed by sclerosis, situated in and extending for a variable distance along the dorsal region of the spinal cord. The ascending change was prolonged upwards into the cervical region, it diminished in intensity as it ascended; topographically it corresponded, more or less exactly, to the distribution of the lateral pyramidal tract, and finally it disappeared in the upper part of the cord.

Gombault and Philippe have described similar instances of "retrograde degeneration" in two cases of syringomyelia and two of myelitis; in one of the cases of syringomyelia there was ascending sclerosis of the anterior pyramidal tract, as well as of the lateral.

This retrograde alteration possesses the following characteristics, which distinguish it from Wallerian degeneration. It is of tardy development; it undergoes a gradual diminution in intensity and extent as it ascends, and it has certain quite distinctive histological features. These are, that on transverse section the affected tract seems to be riddled with circular or oval lacunæ of varying dimensions; examined more closely, these lacunæ appear to be altered and enlarged nerve fibres. In the centre of some an axis cylinder is still clearly visible; often normal, sometimes swollen and not susceptible to stains. The spaces frequently contain *débris* of an indefinite nature, and the delicate rim investing them is probably the altered neurilemma or primitive sheath, the myelin of the fibre having disappeared. Throughout the affected tract healthy fibres are disseminated; these increase in number as one ascends, but in the immediate neighbourhood of the lesion the lacunæ greatly preponderate.

The method of Marchi only shows scattered fibres undergoing degeneration. This retrograde change might receive divers interpretations, but, as Gudden, Forel, Monakow, and Darkschewitch have shown, when a system of fibres becomes separated

from its trophic centre, it, as a matter of fact, degenerates in two directions, centripetally as well as centrifugally, but the centripetal degeneration is the least pronounced, is best observed in young animals, and only evidences itself after a more or less prolonged period. The latter condition was fulfilled in all Sottas' and Gombault and Philippe's cases.

It would appear that the changes in the spinal cord in "retrograde degeneration" bear some resemblance in a pathological sense to those seen in the cord in certain cases of amyotrophic lateral sclerosis, viz., those cases in which the disease first definitely proclaims itself in the spino-muscular neuron, and thence spreads upwards along the cortico-spinal neuron, and not those cases such as one described by Mott, in which the degeneration seemed to appear more or less simultaneously along the entire motor neuron. To explain the degeneration of the motor neuron in amyotrophic lateral sclerosis, neuro-pathologists, accepting the neuron theory as their basis, assume that its initial cause is some obscure loss or diminution of function in the trophic cell of the neuron, situated in the motor cerebral cortex or the anterior cornu of the spinal cord. Now, it is readily conceivable that retrograde sclerosis can be explained on the same theory, for, given an initial destructive lesion in the course of any neuron, we, in the first place, have a more or less immediate necrosis of the distal portion of that neuron; then, secondly, since there is no further call for the service of the central nerve-cell, either in its motor or its trophic function, it can reasonably be assumed that that cell, and likewise the portion of the neuron situated central to the lesion, must naturally undergo a slow process of atrophy, which will ultimately lead to total decay.

If the above view be correct, then it is evident that "retrograde degeneration" cannot possibly be confined to the pyramidal tracts, but must affect other systems of fibres in equal measure, and evidence that this does occur is forthcoming, for on closer examination of sections of the spinal cord from a case of old-standing thrombotic destruction of the cerebellum, which I reported some years ago, in which there existed a degenerative sclerosis of the direct cerebellar tract in its entire length, I find that they present all the histological characteristics of "retrograde degeneration," and I now feel convinced that the case should be ranged in that category. An instance of "retrograde degeneration" occurring in the ascending antero-lateral tract of Gowers' has also been recorded by Gombault and Philippe. Furthermore, the changes in the nervous system to be found after the amputation

of extremities, viz., the spinal hemiatrophy, the disappearance of groups of nerve-cells in the anterior cornua which are known to be related to groups of muscles in the amputated part, must be ascribed to a similar process.

LITERATURE ON THE PYRAMIDAL TRACTS.

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(A) COMMA-SHAPED TRACT OF SCHULTZE AND (B) OVAL CENTRE OF FLECHSIG.

In the *Archiv. für Psychiatrie* for 1883 will be found Schultze's original report of the case of spinal compression in which, in addition to other tracts, this small bundle of fibres in the postero-external columns which now bears that writer's name was found degenerated. Schultze described the bundle as appearing on transverse section in the form of a comma-shaped line in the postero-external column, a line running parallel to the inner edge of the posterior cornu, with its anterior extremity not quite reaching the posterior commissure, and its posterior extremity stopping short some distance off the periphery of the cord. Schultze was unable to follow degeneration in it more than two or three centimetres below the site of the lesion, and supposed that the bundle was composed of descending offshoots of posterior root fibres, a view which we now believe to be incorrect.

It must be mentioned that "kudos" for the discovery of this particular descending degeneration in the posterior columns should not be solely allotted to Schultze, for Bastian, as early as 1867, in a case of injury to the spinal cord in the cervical enlargement mentions such a change, and likewise Kahler and Pick, Strümpell, and Westphal, prior to Schultze, published cases exhibiting analogous degenerations.

More recently detailed descriptions of important cases observed by Gombault and Philippe working conjointly, Barbacci, Tooth, Bruce and Muir, and Hoche, serve to fill up many blanks in the anatomy and connections of this curious tract.

Tooth's case was one of fracture of the spine with consequent almost complete transverse myelitis between the eighth cervical and the first dorsal segments. Degeneration in comma form could be followed down the cord to between the sixth and seventh dorsal segments, lower, therefore, than in Schultze's case, though the method of Marchi does not seem to have been employed.

Gombault and Philippe, in a lengthy paper on systematised lesions in the white columns of the spinal cord, give a detailed description of this bundle of fibres; they review and criticise the work of previous writers, and fully report valuable cases which throw a flood of light on the matter, and force us to considerably modify our views respecting the regional distribution and connections of the tract. A case of complete sclerosis of the fifth and partial sclerosis of the fourth posterior cervical roots, the change being attributable to Saturnism, is adduced for the purpose of disproving the original view promulgated by Schultze, that the comma-shaped tract is formed by descending offshoots of the posterior root fibres. In the case in question, though the root lesion occasioned the familiar ascending changes above the point of entry of the roots, absolutely no degeneration in the posterior columns below the lesion, such as one would expect if the above-mentioned connection actually existed, was discernible. This view of Gombault and Philippe's does not stand unsupported in the literature, for Tooth previously discredited the connection, observing in the spinal cords of animals, in which the posterior nerve roots had been experimentally divided, that no descending degeneration in the comma of Schultze occurred as a result of the operation.

Two cases of spinal compression, one at the eighth cervical, the other between the fourth and sixth dorsal roots, reported by Hoche, furnish a clue to the termination of this tract. The cords were examined by the method of Marchi, and the fibres of the tract were seen to end above the first appearance of the "oval centre of Flechsig," that is, above the twelfth dorsal segment, by passing into the grey substance of the posterior cornu; and as no other observer has traced the tract lower than this level we must for the present accept Hoche's observations as correct.

We might sum up our remarks on this bundle of fibres by saying that it is a small comma-shaped tract, situated in the postero-external column, which degenerates in a descending direction in consequence of a transverse spinal lesion. It arises in the cervical part of the cord, but in what manner and from what cells is unknown, and it terminates in the grey substance of

the posterior cornu in the lower dorsal region. It is independent of the posterior nerve roots, and is probably a system of endogenous internuncial or commissural fibres.

Hitherto one has only mentioned cases of lesions in the upper dorsal or cervical levels of the spinal cord which have given rise to descending degeneration in the posterior columns. Now there are several most interesting cases on record of lesions at lower levels, which have likewise given rise to a descending posterior column degeneration if anything more pronounced, and the question has arisen whether these descending fibres in the posterior columns in the lower levels of the cord are analogous to the fibres which compose the comma-shaped tract of Schultze in the upper levels. The point has been widely discussed, but as yet no satisfactory conclusion has been arrived at. Here is an epitome of the more important cases. In the first instance Gombault and Philippe, in a case of traumatic transverse myelitis situated at the level of the lumbar swelling, found below Schiefferdecker's traumatic zone, *i.e.*, the zone of complete degeneration, which extends through the breadth of the cord for some few millimetres upwards and downwards from the site of the lesion, descending degeneration in the posterior columns, confined to a wedge-shaped triangular area, situated on each side of the posterior median septum, the apex of the triangle pointing to and reaching the commissure, the base being at the periphery. The extent of the degenerated area proportionately diminished in its downward course, and in sections made at a point immediately above the conus medullaris, the apex of the triangle was situated at a point equidistant between the commissure and the posterior margin of the cord.

Bruce and Muir, in a case of fracture dislocation completely destroying the cord in the upper lumbar region, found by the method of Marchi a similar descending degeneration. At the third lumbar root the diseased fibres became collected along the margin of the hinder portion of the postero-median septum and the periphery of the inner half of the posterior columns. At the level of the fourth lumbar root, the tract extended forward as a narrow band along the side of the septum as far as the posterior commissure. At the first and second sacral roots it had the form of a narrow wedge with its base at the periphery and its apex at the posterior commissure. Below the third sacral root the tract diminished in size as far as the coccygeal segment, but retained its triangular form and its relation to the postero-median septum, and the degeneration terminated by passing forwards into the grey matter at the base of the posterior horn of the same side.

In Hoche's two cases of spinal compression in the cervical and dorsal regions respectively, mentioned above as showing degeneration of the comma-shaped tract of Schultze, there also occurred a degeneration in the lumbo-sacral region, which, judging from his drawings, is identical with that found by Bruce and Muir, and similar to that described by Gombault and Philippe. The special point of interest in Hoche's cases is that they show what the upper course of this tract of fibres is. One segment below the lesion he describes them as appearing in the most lateral and external part of the postero-lateral column; they then gradually retreat along the periphery until at the twelfth dorsal level they reach the posterior median septum, and then assume the position described above in Bruce and Muir's case.

In 1891 Barbacci, also using the method of Marchi, reported a case of an intra-medullary tubercular focus situated at the level of the sixth and seventh dorsal nerve roots in which descending degeneration was found very much resembling that described by Hoche, and Kahler and Pick and Daxenberger have narrated cases which might be placed in the same category.

These observations, therefore, conclusively prove that in addition to the comma-shaped tract of Schultze there is another tract which degenerates downwards in the posterior columns, one of greater length (at least 23 spinal segments—Hoche), arising in the cervical region (Hoche), and terminating in the grey matter of the conus medullaris (Bruce and Muir, Hoche and Barbacci); but what its precise origin and connections above are, and also whether it is related to the comma-shaped tract of Schultze, is undetermined. Hoche and Gombault and Philippe regard it as a commissural tract of endogenous origin, and although, as Hoche emphasises, the comma-shaped tract of Schultze absolutely terminates in the lower dorsal region, and takes no part whatever in the continuation of the tract, yet Gombault and Philippe's suggestion that the two tracts are analogous is a reasonable one, because the following resemblances exist:—Both are situated in the posterior column, both degenerate in a descending direction in consequence of a transverse lesion, and both are independent of the posterior roots. Gombault and Philippe proved the latter point in connection with the lower tract by quoting a case of tabes, in which the fourth, fifth, and sixth posterior sacral roots were completely atrophied, and this group of fibres remained unaffected by degenerative processes, while the remainder of the posterior columns was completely sclerosed. There seems, lastly, to be no doubt that the "oval centre" of Flechsig in reality represents the lumbar segment of this tract, and that the "dorso-

median sacral bundle" of Obersteiner represents the sacral segment of the tract, and as both these names are as unnecessary as they are cumbersome and confusing, we are quite in accord with Bruce and Muir's suggestion, that because it bears a relation to the posterior median septum, analogous to that borne by the "sulco-marginal tract" of Marie to the anterior median fissure or sulcus, it should be called "the descending septo-marginal tract."¹

LITERATURE ON COMMA-SHAPED TRACT OF SCHULTZE AND OVAL CENTRE OF FLECHSIG.

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¹ As the "oval centre," or "medianen Abschnitt der medialen hinteren Wurzelzone," Flechsig described two small longitudinal bundles, running in the posterior columns of the lumbar enlargement, situated one on each side of the posterior median septum, neither reaching the posterior commissure nor touching the periphery of the cord. The shape of each individual bundle is, on transverse section, plano-convex, with the convexity directed outwards, and the two plane surfaces come into opposition at the median fissure, so that the two bundles when viewed together form a bi-convex or oval field, hence the name "oval centre." The integrity of this field in tabes is well recognised, and furthermore, if in a tabetic cord serial sections be made from the lumbar region to the conus medullaris, one can be assured of a reciprocal connection or continuity between this centre and the so-called "dorso-median sacral bundle" of Obersteiner.

INTERMEDIARY BUNDLE OF ANTERO-LATERAL COLUMN
(LOEWENTHAL).

This is a scattered tract, the major part of which occupies the mesial portion of the antero-lateral columns in front of the lateral pyramidal tract; but many aberrant fibres are found towards the periphery in the antero-lateral ascending tract of Gowers, and in the direct cerebellar tract and also in the adjoining crossed pyramidal tract. Loewenthal, in papers published in 1885 and 1886, founded on observations of the degenerations resulting from Schiff's experimental operations on the cerebral hemispheres of dogs, assigned to this tract the position named above, and named it the "*Système intermédiaire ou faisceau intermédiaire du cordon latéral.*" He regarded it as a special system of long fibres, and noticing that the fibres composing the tract did not degenerate after removal of the motor area, he argued that they could have no connection with the pyramidal tracts and the motor cortex, such as was claimed by Schiefferdecker and Singer, who noticed degeneration in the tract after sections of the dorsal cord in dogs previous to Loewenthal's description of it. The fibres of the tract are of larger calibre than those of the lateral pyramidal tract, they are clearly seen to degenerate after lesions of the medulla oblongata or spinal cord, they are most abundant in the cervical region, diminishing in number as they descend, and their course is long, as they have been traced into the upper lumbar segments.

Loewenthal was uncertain concerning the point of origin of these fibres, and though some recent papers clear the matter to some extent, there is at the present considerable doubt on this issue. Perhaps the most valuable paper dealing with the subject is from the pen of Boyce. This observer, in an extended series of observations on cats, found that after complete removal of one hemisphere, a bundle of degenerated fibres could be seen at the level of the anterior corpora quadrigemina, crossing in Forel's decussation in the raphe and proceeding outwards to occupy a position behind the inner border of the crusta and close to the mesial and dorsal aspect of the lemniscus on the side contralateral to the lesion. This bundle so formed could be traced downwards in the pons and medulla oblongata, always maintaining a lateral position, until ultimately it gained the lateral column of the spinal cord, along which it could be followed as far down as the lumbar region. The position the tract occupies in the lateral column corresponds closely with the area assigned by Loewenthal to the "*système intermédiaire,*" and Boyce names his

bundle of fibres the "lateral columnar tract." Boyce found that precisely similar degeneration of the tract followed division of the crus cerebri or hemisection of the spinal cord a little below the pyramidal decussation; but there was no degeneration in it subsequent to removal of the motor cortex. On summing up he states that the fibres "are probably the representatives in the medulla, pons, and mesencephalon of the large descending extra-pyramidal fibres found in the lateral columns of the cord, standing in the same relationship to those as do the fibres in the posterior longitudinal bundle and raphe to the anterior and antero-lateral columns. It is possible that in the cat and the dog this higher 'internuncial' or segmental system is more marked than in the monkey or in man, just as in the latter examples the pyramidal system is far more extensive than in the former."

It will be seen that Boyce, though he gives us an admirable description of the tract as it occurs in the cat, offers us nothing more than a clue to its exact origin; and Langley, in telling us that Bouchard in 1866 observed in man that the field of descending degeneration in the lateral column, which resulted from injury to the medulla oblongata, was more extensive than that after injury higher up, and that he located fibres which come from the medulla oblongata in the lateral border of the pyramidal tract, and named them the "fibres commissurales antérieures longues," helps us little, nor does he bring us any nearer the point when in agreement with Sherrington he informs us that the cortical pyramidal tract is of smaller dimensions than that figured by Flechsig, and proposes the name "descending medullary tract" for these extra-pyramidal fibres.

Degenerations consequent on Lesions of the Cerebellum.—Some experimental work completed by Marchi several years back, at first sight adds confusion to our knowledge of the composition and origin of the intermediary system of fibres, but as we now have ample proof that the writer's observations were erroneous, we may fortunately disregard his conclusions. Marchi found that if a hemi-extirpation of the cerebellum of the ape be effected, a secondary descending degeneration ensued in the spinal cord, which corresponded topographically almost precisely to the regional distribution of the "descending sulco-marginal bundle" and the "intermediary system of the lateral column" combined, and the degeneration extended down as far as the lumbar region. He naturally concluded that this system was a descending one, the trophic centre of which was in the cerebellum. Biedl, working in Stricker's laboratory in Vienna, in a paper founded on a

series of observations on cats, of which he had divided the corpus restiforme, writes in confirmation of Marchi's experiments, and so likewise does Thomas. Three English observers, however, Ferrier and Turner, who worked conjointly, and Risien Russell, are entirely opposed to these views originated by Marchi. Having performed many experiments similar to these initiated by Marchi, they are unanimous in denying the occurrence of descending degeneration in the spinal cord as a sequel to an experimental cerebellar lesion in the lower animals, and firmly express the opinion that the degeneration which Marchi obtained was in reality due to an unintentional wounding of Deiter's nucleus and other structures in the lateral region of the medulla, an accident which it would appear it is difficult, nay, almost impossible to avoid during the operation of cerebellar hemi-extirpation, owing to the proximity of the nucleus to the inferior cerebellar peduncle or restiform body, and an injury which is sufficient in itself to produce the exact spinal degeneration figured by Marchi.

This controversy, therefore, has not only been of value in disproving the existence of a direct descending cerebello-spinal tract, but has also led to a closer definition of the origin of Loewenthal's tract, for Risien Russell, who has studied the matter more laboriously than any other observer, in his last paper arrives at the following conclusions :—That the real source of origin of the descending antero-lateral tract, which degenerates in the spinal cord after a lesion of the lateral region of the medulla oblongata, is, as Ferrier and Turner agreed, Deiter's nucleus; that the degenerated fibres, which reach the anterior columns of the upper part of the spinal cord after a lesion of Deiter's nucleus through the posterior longitudinal bundles, are quite distinct from the above tract, and probably belong to some system of internuncial fibres similar to those traced by Boyce to the anterior columns by way of the posterior longitudinal bundles, after hemisection of the mesencephalon; and lastly, that the direct descending tract of degenerated fibres met with in the spinal cord, in close relationship to the fibres of the crossed pyramidal tract, after a lesion of the lateral region of the medulla, is probably identical with the tract described by Boyce after hemisection of the mesencephalon.

An example of the perplexity occasioned by acceptance without confirmation of Marchi's observations is afforded by a recent paper of Bechterew's. This writer describes a system of fibres equally scattered throughout the lateral pyramidal tracts, which is to be observed in the spinal cord of a fœtus at a time when the ordinary pyramidal fibres are still unmyelinated, and which are untouched in an ordinary secondary descending de-

generation, and on the strength of Marchi and Biedl's observations, he states that they degenerate after idio-lateral cerebellar hemi-extirpation, but it is much more probable that they are aberrant fibres of Loewenthal's intermediary system.

LITERATURE ON INTERMEDIARY BUNDLE OF ANTERO-LATERAL COLUMN (LOEWENTHAL).

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DESCENDING SULCO-MARGINAL BUNDLE (MARIE).

"Système descendant de la zone sulco-marginale" is the name affixed by Marie to a scattered group of fibres, situated in the anterior columns along the margin of the anterior fissure, which undergo degeneration in a downward direction in consequence of a transverse spinal lesion. The length of these fibres

varies; some have been traced from the cervical to the lumbar segments. Though they possess a similar distribution, they are not, as Schiefferdecker thought, aberrant fibres of the direct pyramidal tract, for they do not degenerate after cerebral lesions, and are further to be found in the lower segments of the cord, where the direct pyramids are not represented (Flechsig, Singer). In the dog Singer and Münzer place the fibres of this tract in a small group at the anterior angle of the cord, opposite the mouth of the anterior spinal fissure. In the cat it occupies a similar position, and Schäfer has shown that in that animal this bundle is one of the earliest to undergo secondary degeneration, its fibres exhibiting the characteristic reaction with osmic acid on the fourth day after a spinal hemisection.

Marie thinks it probable that these fibres appertain to the system of longitudinal or internuncial fibres, the existence of which Ramon y Cajal and Golgi have so beautifully demonstrated, and that, originating from an upper cell of the anterior cornu, they cross by the anterior commissure, and course downwards to connect that cell with one situated in the opposite anterior cornu of a lower segment of the cord. We fear that there is insufficient anatomical evidence for the existence of the anterior commissural decussation which Marie alludes to, and since destruction of Deiter's nucleus gives rise to descending degeneration of fibres situated in the sulco-marginal zone, indistinguishable from Marie's fibres (*vide* last paragraph), we would rather assume that the trophic centre for this system of neurons is situated in that nucleus or thereabouts. In man the bundle demands further investigation.

POSTERO-EXTERNAL COLUMN OR COLUMN OF BURDACH, AND POSTERO-INTERNAL COLUMN OR COLUMN OF GOLL.

Since the fibres which compose these columns are derived from a like source, and since Goll's column is really made up of overflow fibres from Burdach's column, it is deemed advisable, as well as convenient, to consider the two together.

Within the past few years these columns have been exhaustively studied by a host of competent observers, some describing the changes in them consequent on division of the posterior nerve roots or spinal hemisections in lower animals (Tooth, Horsley, Mott, Sherrington, Singer and Münzer, Barbacci), others reporting the degenerations attendant upon traumatic lesions or tumours,

&c., of the cord or posterior nerve roots (Schiefferdecker, Gombault and Philippe, Déjérine), and others studying the alterations occurring in them as a result of various diseases (Mayer, Redlich, Obersteiner). In short, our knowledge of these two great centripetal tracts has been increased by leaps and bounds, and at the present time is practically complete, with the exception that the ultimate distribution of the tracts after the fibres quit the nuclei of Goll and Burdach still requires further elucidation.

Development.—Flechsaign's development researches show that the fibres of the column of Goll become myelinated at the end of the sixth month of foetal life, and thus are among the earliest fibres to assume the medullary envelope; and Schäfer in his experiments on cats found that the fibres of the column of Goll degenerated on the fourth day after a hemisection of the cord, and was one of the first tracts to yield evidence of the secondary changes. There is, therefore, a parallel between the time of accession of the secondary degeneration and the period of development of the medullated sheath in this column.

Origin and Destination.—From the degenerations observed after section of the posterior nerve roots, and from diseased conditions affecting these roots, numerous writers have demonstrated that the fibres composing these columns represent the spinal continuations of these posterior roots—in short, they are exclusively exogenous fibres. Although a side issue, it should here be indicated that in certain of the lower animals, such as the frog, chick, &c., a certain number of fibres having an intra-spinal origin issue in the posterior root, and hence do not degenerate in consequence of a root section (v. Lenhossek, Ramon y Cajal, Horton Smith), and the question has arisen whether analogous fibres do not exist in mammals and the human being. But in the case of the cat and the monkey Sherrington, v. Lenhossek and Ramon y Cajal's observations definitely negative this idea, and therefore the original law of Bell, which states that the posterior roots exclusively consist of fibres of extra-spinal origin destined for the conduction of sensory impressions, certainly holds in the case of some mammals, and probably also in the human being.

The fibres of the posterior roots enter the cord in that region which is situated behind the substantia gelatinosa Rolandi, and the most laterally situated fibres of this portion form Lissauer's so-called rootzone. It has been noticed by Obersteiner that just at the point of entry into the cord each fibre dispenses with its medullated sheath, but only for a very brief distance. From personal observations I am convinced of the correctness of this statement, and may mention that this gap in the medulla of the

fibres may be most clearly seen if an acutely degenerated posterior root be stained by the method of Marchi.

Having gained their entry into the spinal cord, the fibres divide into ascending and descending branches, each of which issue collaterals in their course. The descending branches pass downwards for a short distance, and then turn at right angles into the grey matter at the top of the posterior cornu, where they end in arborisations round nerve cells. The ascending branches have varying destinations, and either by means of their terminal branches or their collaterals are said to come into relation with a number of different groups of nerve cells; certainly many fibres go to (a) cells in the middle segment of the posterior cornu; others seem to be destined for (b) the motor anterior cornual cells, and form the reflex collaterals of Kölliker or postero-anterior collaterals of Ramon y Cajal; others proceed to (c) the cells of Clarke's column, and are seen atrophied in *tabes dorsalis*; a small number of collaterals cross in the grey commissure and go to (d) cells in the posterior cornu of the opposite side; and, lastly, the long fibres of the columns reach (e) the cells of the nuclei of Goll and Burdach. The researches of Ramon y Cajal, v. Lenhossek, Golgi and Kölliker seem to prove that these fibres, when they approximate these various groups of nerve cells, break up into arborisations which surround the bodies of the cells without visibly coming into contact with them or penetrating their interior; so that if a recently degenerated nerve fibre be followed up to one of the nerve cells, delicate methods may display a disappearance of the investing arborisation, while the cell body and its processes remain intact. But that this cell body or "Endkerne," as His calls it, so shorn of its investing diminutive nerve plexus, undergoes degeneration and disintegration at a later stage is almost certain.

In addition to the above-mentioned destinations of the posterior root fibres, others are supposed by Loewenthal, Oddi and Rossi and Berdez, on the strength of experimental researches, to pass by way of the anterior commissure either into the opposite posterior column or to enter one of the long ascending tracts of the anterior or lateral columns, but the existence of such a decussation is denied by more recent observers. Fajersztajn asserts that the posterior roots have no connection whatever with the anterior commissure, and bases his statement on convincing deductions drawn from experiments on animals; these were the isolation of lengths of the spinal cord by two complete transverse sections made at distances of 6-14 centimetres from one another, and in these cases he found the anterior commissure perfectly

free from degeneration in the neighbourhood of the lower hemisection, where all ascending fibres must necessarily be degenerated. Souques and Marinesco and Mott share this opinion, and the latter mentions the supposition that if degeneration occurs in the crossed afferent tracts of Gowers and Edinger (*vide* antero-lateral ascending tract) it might be attributed, not to the section of the posterior roots, but to unavoidable vascular injuries incident to such an operation affecting nerve cells in the grey matter of the posterior horn, from which it is believed the fibres of the crossed afferent tract of Edinger originates. These latter fibres, it must be noted, are supposed to cross in the anterior commissure.

Lastly, certain physiological experiments point to the probability of a decussation of fibres, either by way of the grey commissure, or directly through the posterior median septum to the opposite side, but no anatomical basis exists for this supposition.

Topography.—Having now indicated the latest views concerning the destinations of the posterior root-fibres, it will next be necessary to refer in some detail to the topographical distribution and arrangement of the individual groups of posterior root-fibres, commencing with those derived from the cauda equina.

Excellent cases, illustrating the course of the degeneration which follows destruction of the cauda equina in the human being, have been recorded by Souques and Marinesco, Darkschewitch, and Déjérine and Sottas; and the following descriptive *résumé* of Souques and Marinesco's case applies more or less to all, and may be accepted as typical. In this instance the cauda equina and conus medullaris, and the three lower sacral segments, were destroyed by the pressure of a group of hydatid cysts. The middle sacral segments exhibited the changes of traumatic degeneration (Schiefferdecker); in the upper sacral segments the entire posterior columns, with the exception of the centrum ovale (Flechsig), the cornu-commissural zone (Marie), and some few fibres coursing along the inner margin of the posterior horns, were degenerated; likewise the delicate myelinic plexus, situate in the grey matter of the posterior and anterior cornua, was at this level markedly atrophied. In the mid-lumbar region similar changes were visible. In the lower dorsal region the degenerated area was separated from the posterior cornua by a definite intervening zone of healthy fibres, and the myelinic plexuses in the anterior cornua were healthy. In the mid-dorsal region the plexus of nerve fibres in the posterior cornua regained a healthy appearance, and the patch of degeneration assumed the form of a funnel or wedge, the point of which reached the posterior commissure, while the base lay

along the periphery. In the upper dorsal region the degeneration became limited to the postero-internal columns, and retreated from the commissure. In the cervical region it affected only the posterior half of the postero-internal columns, and in the medulla degenerated fibres were traceable to the inner side of the nucleus of the funiculus gracilis. Lastly, it should be added that the total volume of the degenerated fibres gradually diminished as the diseased field ascended.

Tooth obtained degeneration resembling this in its distribution, after division of the posterior roots of the cauda equina in the monkey; and Mott, after section of the lumbo-sacral roots in the monkey and cat, got confirmatory results.

The experiments performed by Tooth of division of all the posterior nerve roots between the third dorsal and the third lumbar segments, inclusive, produced like results. The patch of degenerated fibres was situated immediately external in position to that above described, and likewise gradually spread inwards, until in the upper dorsal region it was almost confined to the postero-internal column; then, as it extended along the cervical region, it gradually retired from the posterior commissure, while maintaining its peripheral base. The degenerated fibres terminated mainly in the outer part of the nucleus of the funiculus gracilis.

In the case of the first and second dorsal nerve roots and the two lower cervical roots, some of their fibres pass over to the postero-internal columns, but a portion do not leave the column of Burdach, and in regard to the remaining upper cervical nerve roots, their fibres canton for their entire course in the postero-external column, gradually taking up a more internal position as they ascend, and ultimately gaining the nucleus of the funiculus cuneatus.

A case narrated by Gombault and Philippe, in which there was complete destruction of the fifth right posterior cervical root, and partial destruction of the fourth posterior cervical root on the same side, beautifully illustrates the degeneration as it occurs in the cervical region in the human being. Immediately below the fourth cervical roots, the patch of degeneration is triangular in shape, approximated to the posterior part of the cornu, and separated from the periphery by a thin band of healthy fibres. At the level of the first cervical roots it is seen as a strip, extending from the periphery to the posterior commissure along the inner margin of the postero-internal column. It occurs as a similar strip in the funiculus cuneatus at the first cervical level, and eventually becomes localised in the cuneate nucleus.

From these accounts it may readily be gathered that the long fibres derived from the posterior roots possess one remarkable peculiarity in regard to the course which they pursue, viz., that as they ascend they are gradually being pushed into a more internal position, and having the position which they have just vacated occupied by fibres which enter from the root immediately above. In this manner it comes about that those fibres which occupy the external division of the posterior field in the lower segments of the cord are found in the internal division in the upper segments. This assumption of an eccentric position by the long fibres of the posterior roots is one which is common to a number of other systems, and has led Flatau to formulate the law "that the short fibres of the cord run in close position to the grey matter, while the long fibres select a position next the periphery."

Numerous other reports of the degenerations which have ensued after various forms of transverse lesions in different parts of the spinal cord, and many other experimental researches, might be cited in illustration of the topographical distribution of the posterior root fibres. But this is hardly necessary, and it may be taken for granted that the sum total of these observations is (1) that the fibres which constitute the postero-internal column or column of Goll and eventually enter the nucleus funiculus gracilis, are derived from the posterior roots of the sacral and lumbar segments and of the dorsal segments, with the exception of the first and second, and that all the fibres which enter into the composition of this tract have in one part of their course cantoned in the column of Burdach; (2) that those fibres which constitute the postero-external column or column of Burdach, and terminate in the nucleus funiculus cuneatus, are derived from the posterior roots of the cervical segments, and partly from the two upper dorsal posterior nerve roots.

Distribution of the fibres which emanate from the nuclei of the funiculus gracilis and funiculus cuneatus.

As already stated, considerable doubt exists concerning the ultimate distribution of the fibres issuing from Goll's and Burdach's nuclei, or the fibres of the second sensory neuron as they might be called; the reason, of course, being that lesions which will cause an interruption of these secondary neurons alone, without involving other tracts, are rarely met with. However, the accepted view is, that these fibres are destined for the cortex of the cerebrum and cerebellum respectively, that they are

conveyed to the former in the fillet or lemniscus, to the latter by the corpus restiforme or inferior cerebellar peduncle.

In the first place, in regard to the fillet, articles sufficient to form a considerable volume have been published bearing on its course and connections, but it will be impossible in this review to do more than outline some of the more important observations on the tract.

To begin with, some experimental anatomical papers dealing with the course of these fibres are of interest. Mott, after unilateral separation of the nuclei of the posterior columns from the arciform fibres issuing therefrom in the monkey, obtained degeneration of these fibres and of the opposite inter-olivary layer. In the upper part of the pons varolii the degenerated fibres occupied the median and lateral fillet; some fibres of the lateral fillet apparently went to the corpora quadrigemina, but the majority of the remaining fibres could be traced onwards to the optic thalamus, where they terminated. Evidence of a direct continuity of these degenerated fibres by a "cortical fillet" with the cortex cerebri was not obtainable.

Likewise Singer and Münzer, by destroying the cuneate nuclei, obtained atrophy of the internal arciform fibres of the same side and of the fillet of the opposite side, which was traceable to the optic thalamus.

von Vejas also years ago discovered that destruction of the posterior column nuclei of new-born animals induced atrophy of the same part of the fillet as far as the corpus trapezoides.

Schlesinger, in a most thorough paper on degenerations of the lemniscus well worthy of consultation by anyone specially interested in this tract, traces some fibres of the posterior column nuclei to the anterior corpora quadrigemina and the majority to the optic thalamus. All Schlesinger's observations were made on the human being.

From the foregoing it might be assumed that these fillet fibres issuing from the nuclei of Goll and Burdach's column degenerate only in an ascending direction, but this is not so, for there is an opposite array of evidence to show that they may degenerate or atrophy in a descending direction. Jakob, Mahaim and Bruce have reported such a descending degeneration in cases of central cerebral lesions, and the writer, in a case of tubercular softening of the optic thalamus, examined by the method of Marchi, saw descending degeneration in this tract.

Therefore, though confusing, it seems, nevertheless, to be correct to assume that the fibres of the fillet may degenerate either upwards in consequence of an interruptive lesion near the medul-

lary nuclei, or downwards in consequence of a lesion of the great nuclei at the base of the brain.

Now, since an interruptive lesion of the fillet gives rise to a degeneration which cannot be traced higher than the optic thalamus, the question is, how are sensory impulses conveyed further to the cortex cerebri? And the supposition is that between the thalami and the cortex a third neuron is trajected, which has been named by some the "cortical fillet," and which may under certain conditions undergo degeneration. For instance, Monakow, by destroying the parietal lobe in young animals, produced atrophy of the fillet of the same side and of the internal arciform fibres and nucleus gracilis. Flechsig and Hosel saw the same changes in a case of porencephaly involving the central convolutions; similar cases to this have been recorded, and in two cases of cerebral lesions above the level of the basal nuclei, I have noted corresponding atrophy of the fillet.

We may then sum up by saying that the fibres issuing from the nuclei of Goll and Burdach's columns, which are destined for the cortex cerebri, ascend in the lemniscus or fillet. These fibres decussate in the medulla, continue along the pons and crus cerebri in the mesial and lateral lemniscus, and after giving off collaterals to various nuclear structures, amongst others the anterior corpora quadrigemina and the corpora Luysii, they eventually reach the optic thalamus. At this level it is supposed a third system of sensory neurons begins, the axons of which are first grouped in that part of the posterior limb of the internal capsule which Charcot has named the "carrefour sensitif," and thence stream into the corona radiata to terminate in the cortex of the parieto-occipital and temporal convolutions. But more information on this system of neurons is needed.

Secondly, one must briefly refer to the connection between fibres issuing from the posterior column nuclei and the opposite lobe of the cerebellum. According to Monakow the fibres issuing from the cells of the outer or lateral part of the nucleus of Burdach's column are specially destined for the cerebellum; these fibres are joined by others from the nucleus gracilis, and are directed to the restiform body by the internal arciform fibres, and hence reach the cerebellum, but what part thereof is not exactly known.

According to Bechterew the nucleus gracilis has another crossed connection with the cerebellum; this writer states that some few of the fillet fibres at the decussation of that structure, instead of continuing upwards, pass forwards through the opposite anterior pyramid, and reaching its ventral surface, curve round

the periphery of the medulla oblongata as external arcuate fibres to the corpus restiforme, and thence reach the cerebellum.

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LISSAUER'S ROOTZONE, OR COLUMN.

As Lissauer's rootzone, Waldeyer's "Markbrücke," or Flechsig's "laterale hintere Wurzelzone," is recognised that part of the cord which on transverse section lies immediately dorsal and lateral to the apex of the posterior cornu. All that we know about the area is that it contains fibres of small calibre, supposed to be derived from the posterior roots, and that they proceed in through the substantia gelatinosa to cells of the posterior cornua. Lesions which cause ascending degeneration in the posterior columns also

give rise to degeneration of Lissauer's column, and it is invariably sclerosed in *tabes dorsalis*. Bechterew has indicated that the fibres of this column are peculiar in becoming myelinated at a later period than any other of the posterior root fibres.

DIRECT CEREBELLAR TRACT.

The name given to this important afferent tract by Flechsig, its original describer, was "the direct lateral cerebellar tract," but it is now occasionally called the "dorso-lateral, or postero-lateral, ascending cerebellar tract," in contradistinction to the "ventro-lateral or antero-lateral ascending cerebellar tract," *i.e.*, the antero-lateral ascending tract of Gowers.

Development.—The fibres of the tract acquire their medullated sheath not later than the beginning of the sixth month of foetal life (Bechterew), which is considerably prior to the period of medullation of the fibres of the antero-lateral ascending tract.

Origin.—In regard to the origin and constitution of this tract, we are, as Marie says, even at the present time, in a condition of absolute uncertainty. The two main views in reference to its origin are (1) that the fibres are derived from the cells of the vesicular column of Clarke, a view championed by Mott; (2) that they are derived from the posterior roots, a mode of origin credited by Tooth.

Mott describes how "the cells of the column of Clarke give off large fibres which run upwards, slightly forwards, and then outwards through the lateral column, to reach the direct cerebellar tract of the same side." And while admitting that on account of the obliquity of the course followed by these fibres between their starting-point in the vesicular column and their cantonment in the direct cerebellar tract, it is impossible to cut a section which will include a view of the fibre in the whole of this part of its course, yet he adduces a quantity of evidence—histological, developmental, and experimental—in favour of his claim. Perhaps the most important experiment in support of the view was that of unilateral section of Clarke's column, effected in a monkey at the level of the twelfth dorsal and first lumbar segments, which resulted in ascending degeneration of the direct cerebellar tract on the side of the lesion. Sherrington acquiesces in Mott's views, and they are further supported by Flechsig's developmental researches.

Touching the second theory of origin, Tooth agrees with Mott in thinking that the fibres of the tract do not come by way of the

posterior roots for the lower limbs, but he found that if in monkeys he divided the 6th, 7th, and 8th cervical and the 1st dorsal posterior nerve roots, a complete and absolute degeneration—not of the whole direct cerebellar tract, but of that part of it which lies next the posterior horn—occurs. Like results followed section of the 2nd, 3rd, and 4th dorsal posterior roots. He therefore concludes that certainly in the cervical region, and probably also in the upper dorsal region, fibres of the posterior roots enter largely into the composition of the tract. It is to be further gathered from Tooth's work that he regards the direct cerebellar tract as being entirely made up of fibres of large calibre (Bechterew supports this statement), and that the fibres of small calibre seen in the position of the tract in the lower dorsal region, are descending ones, probably pyramidal fibres, as the pyramidal tract comes to the surface at this level, and that the fibres which Mott and others have seen obliquely crossing the lateral column at this level are fibres of this nature. Tooth's conclusions are rendered insecure by the fact that Singer, Kahler, and others, in their experiments of section of the posterior spinal roots of the dog, did not obtain degeneration of the direct cerebellar tract.

We should also like to ask why it is the exception and not the rule to find sclerosis of the direct cerebellar tracts in cases of *tabes dorsalis*, in which disease the posterior roots are completely withered up by sclerotic processes.

Unfortunately the recently recorded observations of two Italian experimental neurologists, Pellizzi and Paladino, are not reconcilable to either of the above-mentioned views, and indeed are altogether extraordinary as well as out of accord with the observations of other better known observers, that is, provided the anatomical distribution of the fibres of the spinal cord be similar in the dog to what it is in the monkey, as we may presume it is.

Pellizzi, after unilateral division of the posterior roots of the last lumbar segment and of the first posterior sacral root, and likewise after a hemisection of the spinal cord at this level, obtained, along with other changes, symmetrical ascending degeneration of both direct cerebellar tracts. A like result followed unilateral section of the four lower posterior cervical roots. He surmises that the direct cerebellar tract receives its fibres partly from the column of Clarke of the same side, partly from the posterior roots of the same side direct, and partly from the posterior roots of the opposite side, the fibres of the latter decussating in the anterior commissure.

Paladino, after unilateral section of the sixth posterior roots of the lumbo-sacral plexus, also obtained bilateral ascending degeneration of the direct cerebellar tracts, and a similar result after unilateral division of the four lower dorsal posterior roots.

Both workers stained their sections by the method of Marchi. Results such as these render our confusion concerning the origin and composition of this tract more profound, but judging from the work of previous experimenters and a quantity of other evidence, we can hardly seriously accept Pellizzi and Paladino's observations as correct, that is to say, as far as the point under consideration, viz., the source of these fibres, is concerned. A difference between the constitution of the cord of the dog and that of the cat or monkey is too unlikely to account for these results, and to my mind they are altogether insufficient to controvert the records of careful experimenters, like Mott and others, who, severing the same roots and employing the same staining method, failed to obtain any degeneration whatever in either direct cerebellar tract, furthermore they are out of harmony with the changes observed in the human cord following lesions of the posterior roots of the lumbo-sacral plexus.

While offering all due respect to Pellizzi and Paladino for their work (Pellizzi's paper is an especially complete one), we therefore feel forced to disregard their conclusions, and hazard the opinion that the anomalous degenerations which their experiments brought forth are to be attributed to some operative mishap, possibly some unnoticed vascular injury, which it is difficult to avoid in these procedures, and which is apt to render any experimental work unreliable.

After sifting all the evidence concerning the origin of the direct cerebellar tract, we are inclined to abide by Mott's decision that it is composed of the neuraxons of the bipolar cells of the vesicular column of Clarke.

Topography.—The level at which this tract commences as a bundle varies with different authors. Tooth concludes from his researches that it begins to show itself somewhere between the 9th and 11th dorsal nerve roots. Mott, and likewise Kahler and Pick, fix it at the 9th dorsal pair, Schultze at the 10th, and more recently Barbacci has observed degeneration in it as low as the point of origin of the 11th and 12th dorsal pair of nerve roots. It is probable that the site at which it appears will vary in different individuals in the same way as the downward distribution of the columns of Clarke is inconstant.

Since it is an established fact that Clarke's column commences to appear at the 2nd or 3rd lumbar segment, and since the direct

cerebellar tract is said to be derived from these cells, the question may be asked: Why is it that after a lesion in the lumbar region where Clarke's column is already formed, degeneration in the direct cerebellar tract does not present itself until the level of origin of the 11th or 12th dorsal nerve roots is reached? This apparent incongruity is explained, as Barbacci and Mott have demonstrated, by the great obliquity of trajectory of the fibres as they course from Clarke's column to their eventual seat in the tract. This obliquity is such that though Clarke's column may be represented as low down as the 2nd lumbar segment, the axis cylinders of the nerve cells of the columns do not become grouped in their position in the direct cerebellar tract until a point two or three segments higher up is reached.

In form the direct cerebellar tract has been compared to the segment of a ring, occupying about one-sixth of the spinal circumference. Its posterior extremity is thickened and comes into contact with the tip of the posterior cornu. Its anterior extremity is attenuated and at the same time not sharply defined, its fibres mingling with fibres of the adjoining antero-lateral ascending tract. Throughout the whole extent of its course in the cord the tract more or less maintains this shape and position, but at about the level of the 3rd cervical roots it becomes separated from the antero-lateral ascending tract by the interposition of a collection of heterogeneous fibres.

Higher Distribution and Destination.—As the tip of the posterior cornu quits the periphery in the lower part of the medulla the direct cerebellar tract takes its place; it is thrust further back, a little higher up, by the so-called ascending root of the trigeminal nerve, which inserts itself in front of it. Higher still the tract proceeds, first externally to the ascending 5th root, and then comes to lie anteriorly to it. At the level of origin of the 8th nerves the fibres pass obliquely into the corpus restiforme. Thence Loewenthal, in experiments on dogs, traced it to the dentate nucleus of the cerebellum, and inferred that it ultimately terminated in the superior vermiform process. Tooth believes that it is only after section of the posterior roots of the upper segments of the cord that a simple uncomplicated degeneration of the direct cerebellar tract can be satisfactorily traced upwards, because in hemisections of the cord there is a confusing admixture of degeneration of the antero-lateral elements. Bechterew, however, in developmental observations on the fœtus from 25-27 centimetres long, confirms the statement that the direct cerebellar tract passes to the superior

vermis, and Monakow and Mott arrive at the same conclusion experimentally.

Retrograde Sclerosis or Degeneration in the Direct Cerebellar Tract.—In 1894 I reported a case of old standing thrombosis of the posterior inferior cerebellar artery which had left a deep and extensive excavation, involving the parts supplied by that artery. Microscopic examination of the cord in this instance revealed profound sclerosis of the direct cerebellar tract occurring throughout the whole extent of this tract, and this was accompanied by atrophy of the cells of Clarke's column, all on the side of the lesion. Now, the only rational conclusion is that the case was one of retrograde sclerosis in consequence of an obliteration of the terminus to which the fibres of the direct cerebellar tract run. More recent publications show that such a retrograde sclerosis may occur in other tracts and so confirm the view.

Pellizzi, after a lesion at the lower dorsal level, and after unilateral section of the four lower posterior cervical roots, obtained slight descending degeneration in the direct cerebellar tract on the side of the lesion. A result, so far as one can gather, never obtained by other experimenters. He explained the degeneration by supposing that the degenerated fibres are descending branches of the posterior roots.

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ANTERO-LATERAL ASCENDING TRACT, VENTRO-LATERAL ASCENDING CEREBELLAR TRACT, OR TRACT OF GOWERS.

This is another important tract which degenerates in an ascending direction in consequence of a transverse spinal lesion, and which has received a lot of attention from those workers who have

studied the direct cerebellar tract, with which it was formerly confused. As will be presently indicated, the cerebellum seems to be its destination, and on that account some writers *e.g.*, Mott, Loewenthal, Schäfer, prefer to name it the "ventro-lateral or antero-lateral ascending cerebellar tract." By Continental writers it is generally called after its original discoverer, "Gowers' Tract."

Origin.—As was the case with the "direct cerebellar tract," so is it with the antero-lateral ascending tract, the exact source of the fibres which compose it is uncertain—perhaps to a greater degree—and the views concerning its origin, whether formulated by experimental or purely anatomical workers, are mainly based on conjecture. That the fibres which constitute the tract enter the spinal cord by the posterior roots would appear to be in a measure negatived by the experiments of division of these roots practised by Mott, Tooth and many others; but Pellizzi, whose extraordinary results have already been referred to in the section on the direct cerebellar tract, obtained symmetrical ascending degeneration in both antero-lateral ascending columns after unilateral section of the last lumbar and the first sacral posterior roots of the dog; he also saw slight degeneration of the same tract, but more marked on the side of the lesion after unilateral section of the four lower posterior cervical nerve roots, and naturally concludes from these experiments that each antero-lateral ascending tract receives some of its fibres from both posterior roots, the anterior commissure serving as the bridge of decussation.

Likewise Loewenthal, Berdez and Langley and Anderson, after similar operations on various animals, obtained degeneration either in the anterior commissure or in both antero-lateral ascending tracts, but always more marked in the latter on the side of the lesion.

Also Mott, in a recent paper, states that in one monkey, of which he had divided the fourth, fifth, sixth, seventh, eighth and ninth sub-thoracic roots on one side, he found some thirty degenerated fibres in the opposite antero-lateral ascending tract, but he firmly expresses the belief that this degeneration was set up by vascular injuries to the grey matter of the posterior horn, accidentally induced by the operation, and in effect totally denies the passage of fibres from the posterior roots directly across the cord to the opposite antero-lateral ascending tract. Mott, in the same paper, further mentions that Loewenthal and Berdez's experiments are on similar grounds not to be relied on, for they certainly did not exclude injury of the tip of the posterior horn and contiguous parts, nor did they take into account the effect of such

injuries. For a like reason Langley and Anderson's experiments cannot be accepted, and it is more than probable that Pellizzzi's experiments must be condemned on account of the same flaw.

Unfortunately, we can hardly compare the observations of Kahler, Singer and Münzer and Tooth, or any other experimenter who worked before the method of Marchi was introduced, with the observations of the more recent writers quoted above, all of whom worked with this method, for the simple reason that the method of Weigert and its modifications, which a few years back was the fundamental staining *technique*, fails to reveal degenerated fibres which are disseminated or present only in small groups, whereas the method of Marchi will plainly discover such degeneration.

To support the assumption that no fibres enter the antero-lateral ascending tract directly from the posterior roots, we are therefore practically left with Mott's view only, but this view we prefer to accept until an explanation is forthcoming, showing why it is that in certain cases in which the operation of division of the posterior roots is carefully performed, and the sections of the spinal cord stained by the most recent and approved methods and closely examined, no degeneration whatever is discoverable in either ascending antero-lateral tract. It should also be mentioned that Mott's view is strengthened by the fact that in several cases of injury to the cauda equina in the human being, in which the cord was stained by the method of Marchi, no degeneration whatever was found in either ascending antero-lateral tract (Darkschewitch, Souques and Marinesco, Déjérine and Spiller).

What, then, is the source of these fibres? Tooth, whose opinion deserves consideration in this connection, suggests "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 groups in the anterior horns," but this suggestion, he admits, is quite hypothetical. Hadden and Sherrington's case of tabes, in which the antero-lateral ascending tract was sclerosed, as well as the posterior column, which Tooth quotes in favour of the view that the columns of Clarke give origin to fibres of the antero-lateral ascending tract, does not appear to us to be of much importance, because, though atrophy of the columns of Clarke is almost constant in locomotor ataxia, sclerosis of the lateral columns is rare, and when it does occur involves the direct cerebellar tract as often as, if not more frequently than, the antero-lateral ascending tract. In specimens in which we have seen such changes, we

have attributed them to peripheral vascular alterations concurrent with syphilis and tabes (an idea suggested by Déjérine years ago), rather than to a primary atrophy of Clarke's column.

As far as we can gather, Tooth and Testut appear to be the only authors who maintain that the antero-lateral ascending tract takes any fibres from the columns of Clarke, but there is more or less unanimity of opinion that cells in other parts of the grey matter, particularly at the base of the anterior horn, give origin to it (Bechterew, Mott, Flatau, Gombault and Philippe). Some experiments of Mott's are of considerable importance in this connection; he practised median section of the spinal cord in the lumbar region in two monkeys. In the first experiment the lesion involved the lower end of Clarke's column on one side, and the result was symmetrical ascending degeneration of both ascending antero-lateral tracts, and degeneration of the direct cerebellar tract on the side of the lesion. In the second experiment the incision was successfully made in the middle line below the position of Clarke's column, and while precisely similar bilateral degeneration occurred in the antero-lateral ascending tracts, there was practically none in the direct cerebellar tract. Similar results were obtained by Grünbaum after longitudinal division of the cord. Likewise Ehrlich and Brieger, and Singer and Münzer, finding that compression of the abdominal aorta in rabbits causes destruction of the nerve-cells in the grey matter of the lumbar cord, and also ascending degeneration of the antero-lateral ascending tract, infer therefrom that this tract arises from cells in the grey matter of this region.

These experiments, therefore, in a measure, prove that the fibres of this tract do not originate from the nerve cells of Clarke's columns, but from cells elsewhere in the grey matter whose exact situation is unknown, but supposed to be at the base of the anterior horn, possibly the middle cell column of Waldeyer. The occurrence of bilateral degeneration of the tracts in question after a mesial longitudinal spinal section, warrants the assumption that these cells give off fibres which decussate in the anterior commissure, and so reach the lateral tract, and the existence of such a decussation is also supported by Auerbach's experiment of destruction of a considerable length of one-half of the spinal cord in the cat, which resulted in ascending degeneration of the tract on the side opposite to the lesion.

Crossed Afferent Tract of Edinger.—Some other fibres ascending in the position of the antero-lateral ascending tract must not be confused with those which I have just described; these are afferent fibres which Edinger and Gowers, and likewise Mott,

believe enter from the posterior roots to come into connection with cells of the grey matter, which cells give off axis cylinder processes, also decussating in the anterior commissure, and also ascending in the region of the antero-lateral ascending tract; coursing along the medulla oblongata and pons in or near the fillet, these fibres terminate in the corpora quadrigemina or optic thalami. This tract so formed is called the "crossed afferent tract of Edinger," and differs from the antero-lateral ascending tract probably in its origin, and certainly in its destination. From what Mott says, it is probable that it was degeneration of this tract, and not of the antero-lateral ascending tract, which Loewenthal, Berdez, Langley and Anderson and Pellizzi saw in their posterior root experiments; also that that degeneration occurred not in consequence of the root section, but subsequent to accidental injury of the most dorsal segment of the posterior cornu, and therefore that the seat of origin of these fibres is in that segment of the posterior cornua.

Topography and Termination of Antero-Lateral Ascending Tract.

—Having now pointed out the different views concerning the origin of this tract, I will next proceed to deal with its spinal topographical distribution. Firstly, as to the lowest level in the spinal cord at which it has been found. This level is considerably below that at which the direct cerebellar tract first shows itself; as I previously mentioned, degeneration in that tract has not been definitely seen below the 10th dorsal segment, but there are several cases on record of lesions lower than this which caused degeneration of the antero-lateral ascending tract and left the direct cerebellar tract intact; such, for instance, as Schultze's case, in which there was crushing of the lumbar region. Furthermore, Bechterew mentions the existence of the tract even in the lower parts of the lumbar enlargement. If the lesion be below this level, that is to say, if it affect the sacral segments or cauda equina, no degeneration of the tract occurs; this fact is proved by several reported cases of such lesions. In other words, therefore, there is a short stretch of the spinal cord comprising these segments, situated between the 10th dorsal and the last lumbar segment, a lesion of which will cause ascending degeneration of the ascending antero-lateral tract, leaving the direct cerebellar tract intact. And it was from observation of such a case (one of crushing at the 11th dorsal level), that Gowers was enabled to describe the antero-lateral ascending tract as one quite distinct from the direct cerebellar tract, two tracts which had been formerly regarded as one. Bechterew independently confirmed this distinction by adducing developmental proof that

the fibres of this tract become myelinated at the eighth month of foetal life, that is, later than the fibres of the "direct cerebellar tract."

The tract once formed takes up, according to Tooth, the following position: "it 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 rootzone 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 is situated in an area of the cord called by Flechsig the "mixed zone." This position it more or less maintains throughout the cord.

Until some experiments, performed by Mott with a view to determining the destination of the antero-lateral ascending tracts were published, in 1892, great doubt existed concerning the upper course of this tract, though many, following Bechterew's lead, accepted the nucleus lateralis in the medulla oblongata as its terminus. Mott, by a novel experiment on the monkey, that of section of the fibres of the tract in the upper cervical region, by a specially devised instrument, and by the employment of the method of Marchi, was enabled to trace with the utmost accuracy the line of degeneration marking out the bulbar course of the tract. Tooth, in a subsequent paper, amply confirmed Mott's observations. Schäfer and Loewenthal independently arrived at similar results.

The following are the main anatomical points noted by these observers:—At the level of the nucleus lateralis the tract is seen at the periphery external to that nucleus and to the "so-called" ascending root of the fifth nerve. Dorsally, the tract touches the direct cerebellar tract; also many degenerated fibres are visible in the nucleus lateralis itself, thus a connection between the tract and that nucleus is proved, but it does not end there. A short distance higher up the antero-lateral ascending and direct cerebellar tracts separate from one another, and the divergence becomes wider as one ascends. At the level of the olive the ascending antero-lateral tract lies among the external arciform fibres dorsal to that nucleus. In a transverse section catching the sixth and seventh nerves in their intra-medullary course, the tract is still seen at the periphery between the point of exit of these nerves; but also dorsally in the angle formed by the brachium conjunctivum with the lingula, a small mass of degenerated fibres cut transversely becomes visible, and these represent the descending turn of a

loop formed higher up by the passage of the ventral fibres of the tract over and round the root of the fifth cranial nerve. In sections made higher up the two portions of the loop approximate to one another, and at the level of the lowest point of exit of the fourth nerve the extremity of the loop can be discerned as a strip of fibres lying externally to the lateral lemniscus. Having looped in this manner the tract proceeds to the white centre of the superior vermis by way of the superior cerebellar peduncle and valve of Vieussens.

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A LONG SENSORY TRACT IN THE GREY SUBSTANCE OF THE CORD—(CIAGLIŃSKI).

In the *Neurologisches Centralblatt* for September, 1896, Adam Ciagliński draws attention to the existence of a long tract situated in and coursing along the grey matter of the cord,

and although his observation still requires confirmation, it is of such an interesting nature as to demand separate consideration.

Ciagliński drew a tight ligature round the cords of dogs in the lumbar region and killed the animals after from 4-24 hours. The cords examined by the method of Marchi showed, in addition to the usual ascending changes in the posterior columns, a diamond-shaped or rhomboidal area of degeneration situated in the grey commissure; between the ventral extremity of the posterior columns and the central canal, the area was composed of an actual column of fibres which, diminishing in volume as it ascended, was traceable upwards as far as the cervical enlargement.

This writer claims to have seen the tract in the normal human cord, but by this he can only mean a few sparsely disseminated fibres to be found in this region. He believes that its fibres are derived from the posterior roots and physiologically belong to that group of sensory fibres intended for the conveyance of impressions of heat and pain. If this be correct, and it is not an unsupported presumption, having been alluded to by Bellingeri in 1823, and Schiff in 1856, degeneration of the tract may explain certain sensory anomalies (loss of sensations of heat and pain) peculiar to syringomyelia.

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LATERAL LIMITING LAYER.

The lateral limiting layer, as described by Flechsig, is a part of the lateral columns contiguous or adjacent to the grey substance, which in the upper cervical region bounds practically the whole outer side of both cornua, in the cervical enlargement occupies the angle between the anterior and posterior cornua, and in the dorsal region again reaches forwards outside the anterior cornu, but altogether forms a less voluminous bundle than in the upper cervical region. In the lumbar region the layer requires further study.

Flechsig supposed that the layer was made up of fibres derived from two sources, the posterior roots and the cells of Clarke's columns, but we now know that this is incorrect, for, firstly, the layer does not degenerate in tabes dorsalis, nor does section of the posterior roots affect it, therefore it can have no direct con-

nection with the posterior roots ; and, secondly, it is believed that Flechsig mistook for fibres of this layer the neuraxons of the cells of Clarke's column which pass through the lateral limiting layer on their way to the direct cerebellar tract, as described by Mott. It is more likely, as Ramon y Cajal contends, that the layer is composed of fibres which, arising from cells in the anterior or posterior cornua, after a short course either upwards or downwards, again return to the grey matter.

In 1893 Bechterew drew attention to a special bundle of fibres in the posterior portion of Flechsig's lateral limiting layer, which he designated the "mediales Seitenstrangsbündel," he states that this bundle is distinguishable from Flechsig's layer in that its fibres develop their medullated sheath at a later period. It first becomes evident in the dorsal region situated immediately to the outer side of the grey substance between the lateral and posterior cornua, so occupying a portion of the territory between the lateral pyramidal tract and the cornua ; further upwards the bundle advances more to the front, but still remains close to the grey substance. Bechterew, though doubtful concerning its constitution, presumes that its fibres stand in relation to cells in the grey substance, and that these fibres must be of very limited length, as they have never been seen degenerated in the human cord.

In a case of amyotrophic lateral sclerosis recently recorded by Bruce, the interesting point was determined that the anterior or ventral part of the lateral limiting layer had undergone partial sclerosis, while the posterior portion was preserved intact, and since atrophy of the anterior cornual cells is a fundamental change in amyotrophic lateral sclerosis, this observation in a measure proves that the anterior portion of the lateral limiting layer is connected with anterior cornual cells, and it suggests a relation between posterior cornual cells and the posterior portion. The layer may, therefore, be said to be composed of two independent systems which merely agree in that the fibres arise from cells in the grey matter and are of short course. Bruce suggests the names antero-lateral and dorso-lateral for these two divisions, but at the time that he wrote seems to have been unaware of the fact that Bechterew had already given a special description of the posterior division.

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ANTERIOR GROUND BUNDLE OR BASIS BUNDLE.

Excluding the fibres of the direct pyramidal tract, the antero-lateral ascending tract, the crossed afferent tract of Edinger (*vide* antero-lateral ascending tract), and the ascending and descending sulco-marginal tracts, the anterior column is composed of the anterior ground fibres, all of which lie in the immediate neighbourhood of the anterior cornu. The volume and the depth of the bundle varies at different levels. From the degenerative point of view it possesses little interest, as secondary changes in its fibres, even in a case of transverse myelitis, cannot be traced beyond the "traumatic zone." Flechsig and Bechterew, however, in their developmental researches, brought out several important points concerning these fibres; in the first place it was discovered that they received their medullary investment at an early date, viz., the fifth month (considerably earlier than the antero-lateral ascending tract, but not long before the direct cerebellar tract), then it was found that all do not become medullated at once, the first to develop being those which lie in immediate contact with the anterior cornu, and those are supposed to be related to fibres of the anterior roots; others which develop later, it is presumed, are short internuncial vertical fibres connecting cells in different levels of the anterior cornu.

CORNUO-COMMISSURAL BUNDLE (MARIE).

It would appear from experimental anatomical evidence that a bundle of fibres called by Marie the "*faisceau cornu commissural*," situated in that part of the column of Burdach which borders the posterior commissure, and also about the ventral half of the posterior cornu, cannot be grouped with the long fibres of the posterior columns, but must be classed among the short internuncial or anastomosing fibres connecting different levels of the grey substance. This bundle escapes degeneration after root lesions, and topographically corresponds with Flechsig's anterior

rootzone or "ventrales Hinterstrangsfeld," with the exception that, according to Marie's representation, it is hardly so extensive. The tract requires further study.¹

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CHANGES IN THE SPINAL CORD FOLLOWING AMPUTATION OF
EXTREMITIES.

Since the early part of the century, contributions to the literature on this subject have been constantly appearing, and on glancing through the records one finds that while there have been minor differences among the various writers the general results obtained have been tolerably uniform. The predominant alteration is an atrophy of that half of the spinal cord corresponding to the side of the amputation. This has almost invariably been noticed, and is represented by a general reduction in volume of white and grey matter alike, involving those particular segments of the cord which receive and give off the sensory and motor nerves which originally supplied the skin and muscles of the amputated member or part thereof. That the atrophy is approximately confined to these particular segments may be definitely proved, if in a case of amputation these segments be carefully examined and compared with those above and below the suspected level; this was done in two cases coming under my notice, and the results were very definite. That the spinal hemiatrophy has not been definitely localised in this manner by previous writers is obviously owing to the fact that the areas appertaining to the various posterior spinal nerve roots have only been mapped out quite recently; but on analysing records and critically examining published drawings, one finds that the hemiatrophy has almost without exception been noted as being most prominent at the levels which I have emphasised. The cord above and below these levels gradually reassumes its symmetry, and the atrophy is of course not absolutely confined to them.

Studying these changes in greater detail, and in the first place taking the white matter, one finds that though an actual localised

¹ Since the above was written an article by Alexander Bruce "On the Endogenous or Intrinsic Fibres in the Lumbo-sacral Region of the Cord" has appeared in this Journal (part iii., 1897), and therein will be found an excellent description of this set of fibres.

sclerosis may occur, such a change is rare. Marie has reported two such cases, one of amputation of the thigh, another of amputation of the arm, and in both there was ascending bilateral sclerosis in the root area of the posterior columns, most marked on the side of the amputation. Two Italian observers, Guarneri and Bignami, also describe sclerosis of the antero-lateral ascending tract on the opposite side in consequence of an amputation. It appears that for the production of this sclerosis the amputation must be very old standing (in Marie's cases the operation had been performed twenty years previously, and Guarneri and Bignami's bore a similar history). Other changes which are constantly seen in the atrophied white matter are an increase in the nuclei of the neurilemma and an apparent proliferation of the glial elements, but it is worthy of note that though all the white columns of the cord on the side of the amputation may be appreciably reduced in volume, still their staining reaction in all the ordinary methods is practically identical with that of the healthy half.

Next, in regard to the grey substance, it has been mentioned that there is always a concomitant general reduction in its volume, likewise there is a general reduction in number of its contained nerve cells, both large and small, and furthermore there is one special group of cells which, both in the case of amputations of the upper and lower extremities, may be singled out as being particularly prone to atrophy, viz., the postero-lateral group of the anterior cornu. Grigoriew, who is the most recent writer on this subject, is disposed to dissent from this statement, but there is little question concerning its accuracy, for on analysing the literature, one is at once struck with the frequency with which the group is figured or described as having suffered most. Sherrington made a special note of this point in his research on the lumbo-sacral plexus, and uses it in support of his suggestion that in the lumbo-sacral region the postero-lateral group of nerve cells stands related to the intrinsic muscles of the foot. Yet another group of nerve cells which undergoes atrophy after an amputation of the lower extremity is that of the posterior vesicular column of Clarke. Friedländer and Krause first drew attention to this fact, and I noticed it in a case in which I stained my specimens by the method of Nissl.

From the experimental side the subject of the spinal changes after amputations has been vigorously investigated by Homén, and less seriously by Sherrington and others. The former, using the dog as his subject, has succeeded in reproducing most of the changes which have been observed in man; he mentions that

young animals are most suitable for these experiments, and states that in puppies changes commence at the periphery somewhat more than a week after the operation, but in full-grown animals do not appear until one or two months have elapsed.

Friedländer and Krause and Erlitzky maintain that only the sensory neurons atrophy after amputations. Homén's experiments lead him to a similar conclusion, and he publishes apparently convincing coloured plates representing transverse sections of the posterior root ganglia, and showing plainly an intact motor root lying alongside the withered ganglion. But the integrity of the spino-muscular neuron here referred to, or even of the cortico-spinal neuron, can surely only apply to cases of more or less recent amputations, for there is abundant evidence on record to show that not only do the motor roots in course of time atrophy, but also motor anterior cornual cells, and even, likewise, cells in the motor sphere of the cerebral cortex (Charcot and Pitres, Wigglesworth, &c.).

Into the condition of the peripheral nerves in cases of amputation I do not propose to enter at length. The majority of observers state that they are reduced in calibre (Marie has seen them enlarged), the fibro-cellular tissue in them is increased in quantity, the perineurium is thickened, and sometimes myxoid or fatty, and the healthy fibres are reduced in number by about one-half; these changes diminish in severity as one ascends the nerve trunk.

Marie, who in his lectures refers in some detail to the alterations in the peripheral nerves, describes the presence in them of numerous islets, about four times the size of a healthy nerve-fibre, composed of a collection of some five to twenty delicate nerve fibres, possessing an almost imperceptible white sheath. These islets he looks upon as degenerated remnants of an originally healthy fibre, and calls *îlots de dégénération*.

Some writers have described the posterior root ganglia as intact; others have found them diminished in size, their nerve-cells reduced in number, and their nerve-fibre plexus attenuated. We may take it that in old-standing cases of amputation they are always altered in the same way as the anterior and posterior spinal roots are.

What the precise pathology of the changes in the central nervous system after amputations is, is still *sub judice*. Clearly the change in the sensory nerve distal to the ganglion must be a true secondary degeneration, and we might expect atrophy of the sensory neuron above the ganglion in consequence of loss of function. The atrophy of the system of motor neurons may be

of the nature of a retrograde degeneration or sclerosis, similar to that described elsewhere in the cord. Obviously the spinal changes are not the result of a true secondary degeneration, and the distinguishing term "Gudden's atrophy" has been applied to them.

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