BRAIN.

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Original Articles and Clinical Cases.

A STUDY OF THE DEGENERATIONS OBSERVED IN THE CENTRAL NERVOUS SYSTEM IN A CASE OF FRACTURE DISLOCATION OF THE SPINE.

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For the opportunity of recording the following case we are greatly indebted to the kindness of Dr. Cecil Lyster, under whose care the patient was treated at the Bolingbroke Hospital. As it was clear that the accident must have caused a complete destruction of the spinal cord at and below the level of the third lumbar segment, and as the patient survived for a period just within six weeks, it seemed certain that by application of the Marchi method it would be possible to trace completely, besides the posterior column fibres, the following tracts :—

(1) The direct cerebellar tract of Flechsig or the *fasciculus spino-cerebellaris dorso-lateralis.* (Barker.)

(2) Gowers's tract or the *fasciculus spino-cerebellaris ventralis.*

(3) The *fasciculus spino-quadrigeminalis.*[1] } Mott. Patrick.
(4) The *fasciculus spino-thalamicus.* } Tooth.

The following is a brief clinical abstract of the principal clinical facts of the case :—

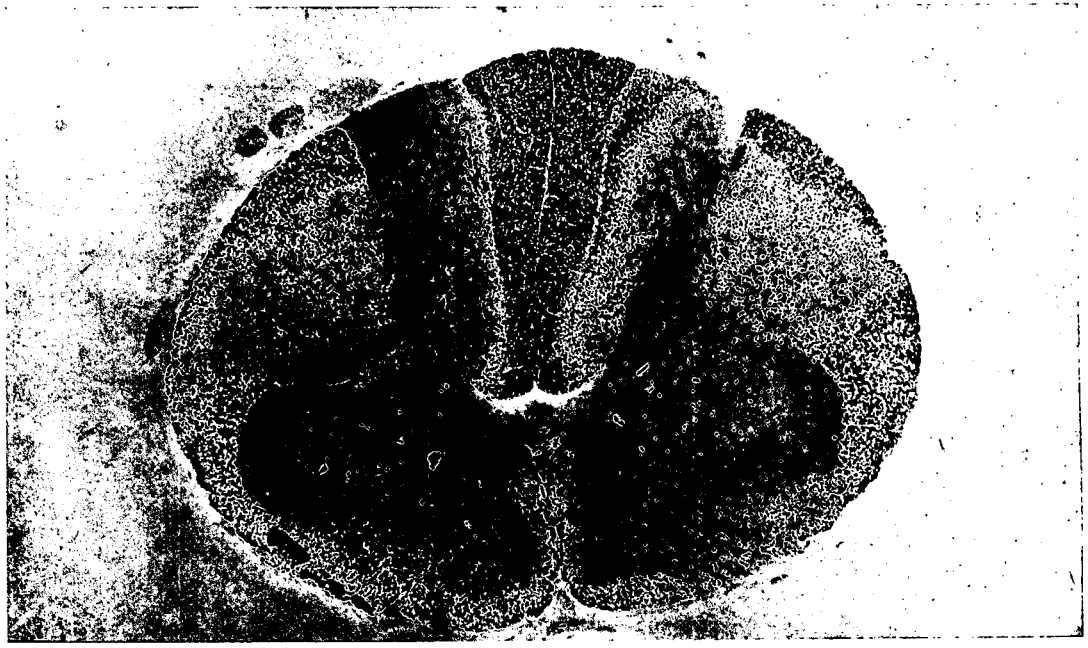
Case of W. L., aged 21, *Bolingbroke Hospital.*

The patient was brought to hospital having been knocked down by an engine and crushed against the edge of the platform. On admission, besides (1) a severe scalp wound in occipital region, and (2) dislocation of the right astragalo-scaphoid articulation with a contused wound of left calf, there was (3) fracture dislocation of the spine in the lower dorsal region. There resulted immediate and complete paralysis and anæsthesia of both legs; all reflexes were absent, and the anæsthesia extended up to the umbilicus. Retention of fæces and urine existed from admission. Cystitis supervened, and though the wounds in the leg were actively treated they showed no tendency to heal. The wasting of both legs and thighs became extreme. No reflexes were ever obtained. The patient died forty days after the accident.

The brain and spinal cord were removed by Mr. H. J. Curtis, F.R.C.S., under difficult circumstances, and for whose assistance in this particular we are indebted. The central nervous system was fixed in formalin 5 per cent. solution and Müller's fluid in equal parts, and subsequently in Müller's fluid alone. For the osmic stain Busch's fluid was employed (solution of osmic acid in iodate of soda solution).

In the crushed area at the level of the fourth lumbar segment the vessels were found to be all thrombosed, the smallest capillaries being engorged with blood. There was also a large extravasation of blood outside the cord, and the crushed substance of the spinal cord had been squeezed upwards (*i.e.*, headwards) beneath the arachnoid for two segments distance, so as to simulate the heterotopic appearance of a double cord.

[1] We would support the use of the expression fasciculus spino-tectalis for this tract as being shorter and more in accord with general morphological terminology.



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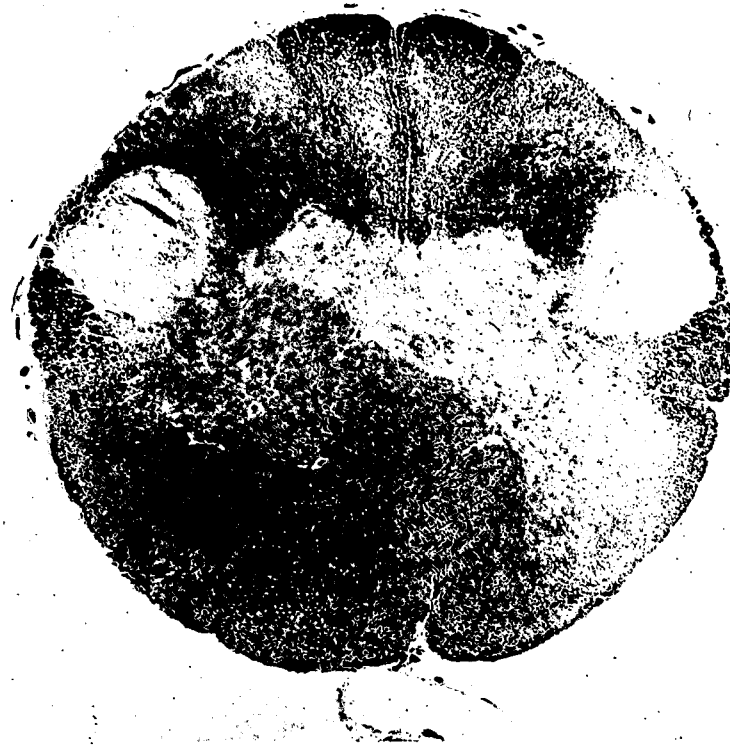

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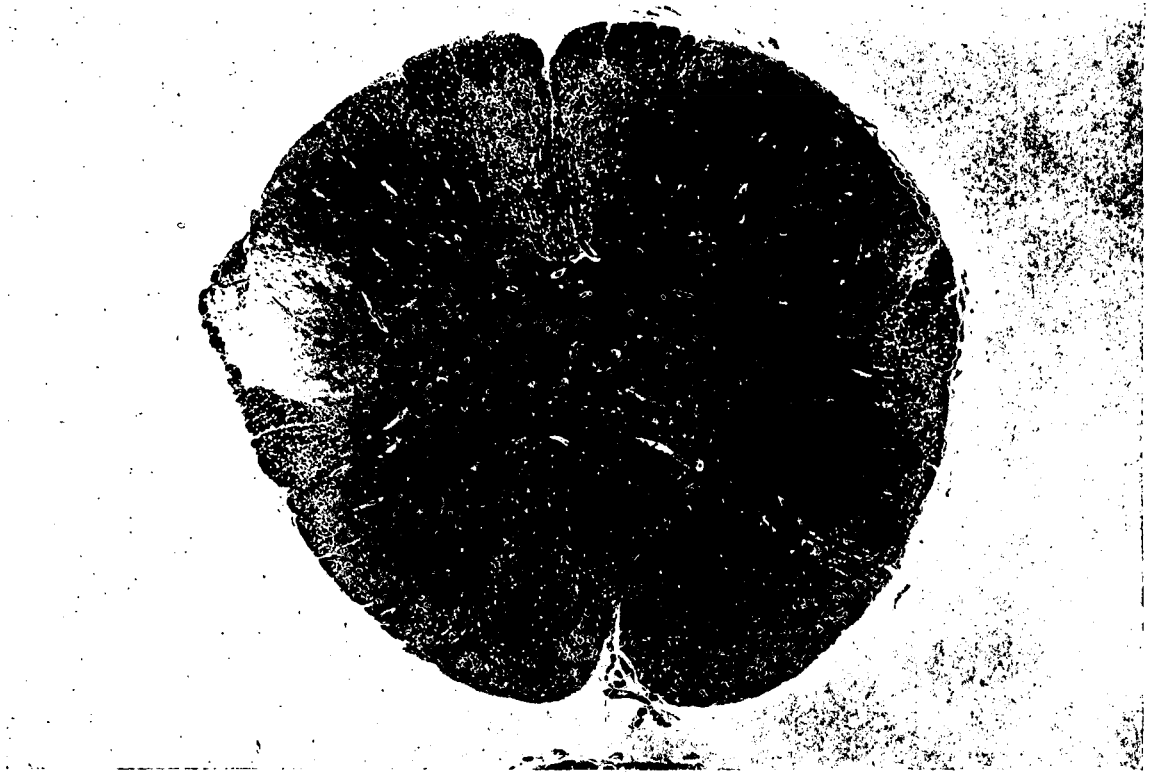

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(1) *The Direct Cerebellar Tract of Flechsig or the Fasciculus Spino-cerebellaris Dorso-lateralis.* (*Barker.*)

This tract is seen in the lowest sections as a bundle of coarse fibres symmetrically degenerated on either side of the cord. It has its customary situation, and extends forward to the ligamentum denticulatum, at which point it is continuous with the antero-lateral tract. At the level of the decussation of the pyramids the degeneration reaches dorsally to the inner border of the subst. gelatinosa on the one side but not on the other; it maintains this relation at the middle of the pyramidal decussation. When the restiform body is fully formed the direct cerebellar fibres occupy its anterior portion. In sections through the lower part of the bulb there are some coarse fibres to be seen lying ventrally to the spinal fifth root; these subsequently pass inwards and dorsalwards, and on examination prove to be only fibres of the direct cerebellar tract taking this somewhat unusual course. The coarse direct cerebellar tract fibres run straight upwards and backwards into the white matter of the cerebellum accompanied on each side by a broad band of fibres which are not degenerated, and which form the olivary division of the restiform body. These direct cerebellar fibres arrive opposite the lateral edge of the lowest folium of the vermis and there branch and subdivide. A few pass under the border of the vermis, but the large majority pass dorsally and spread out into the white matter, and ultimately pass across in the anterior commissure. As the fibres pass backwards they are so arranged that the olivary constituents of the restiform body run caudal to the spinal fibres. As they enter the cerebellum some degenerated fibres can be traced directly to the peduncle of the flocculus.

In the posterior commissure of the cerebellum only half the fibres therein are degenerated, the other (non-degenerated) half are therefore probably olivary in origin.

The direct spino-cerebellar fibres terminate mostly in the superior vermis, and are distributed in diminishing degree in the rest of the cortex cerebelli of each side, the fibres

diminishing in number and calibre, so that the fibres in the posterior superior lobule are extremely fine, whereas those in the superior vermis are both fine and coarse.

The distribution of degenerated fibres to the cerebellar cortex is most marked in the ventral division of the lateral lobes.

So far the arrangement of the fibres observed corresponds with that usually described. We wish now to draw attention to the special relations of the direct spino-cerebellar tract to the structures in the lateral region of the bulb and termination of collaterals derived from the tract. These we will describe according to their morphological appearance, which is that of plexuses.

Fine collateral plexuses in and round the spinal root of trigeminus.—(*a*) *Ventral collateral plexus.* Just above the uppermost level of the decussation of the pyramids strong collaterals springing from the fibres of the direct cerebellar tract as they turn up towards the restiform body pass inwards just ventrally to the spinal trigeminus root and between that and the antero-lateral nucleus. This may be termed the ventral bulbar collateral plexus of the direct cerebellar tract. The fibres ultimately composing it are very fine, and appear to terminate in relation with a nucleus of small nerve corpuscles lying in a plane just internal to the ventral border of the spinal trigeminus root. The uppermost limit of this ventral plexus is the upper border of the auditory striæ. We have found a definite interruption in this plexus for some distance (from 1 to 2 mm.), and that it consequently reappears soon before it finally ends. The nucleus referred to reaches in the formatio reticularis from 1 to 2 mm. higher than the end of the plexus, and is, perhaps, the posterior subdivision of the nucleus lateralis.

(*b*) *Dorsal collateral plexus.*—Another plexus of fine collateral (?) fibres is seen to come from the direct cerebellar fibres, passing inwards and partly through the spinal fifth root. These are collected in a fine plexus just external to the gray nucleus enveloping the fasciculus solitarius, and is, of necessity, especially well defined on the outer side of the gray matter surrounding the fasciculus solitarius. It

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commences below in a plane close above the highest level of the pyramidal decussation. At the level of the upper end of the inferior olive the fibres of the dorsal plexus pass towards the central gray matter, and the plexus receives but few contributory fibres from the external arcuate fibres. The upper limit of this dorsal plexus is the highest level of the auditory striæ.

These fine plexuses, which in our preparations arise directly from the external arcuate fibres, were first noticed by Hoche in a case of transverse lesion of the spinal cord at the level of the seventh thoracic segment (*Archiv. für Psychiat., Bd.* 28, 1896), and Hoche's drawings correspond very closely with our photographs.

It has been suggested, however, by Barker that these plexuses are the termini of spinal fibres ascending through the posterior column nuclei. As already stated, however, we have proved their origin to be from collaterals which arise from the external arcuate fibres.

But for the fact of the marked association in physiological activity between the vagus phenomena of vomiting and nausea and disturbances of equilibration it would be difficult to explain the close connection of the spino-cerebellar system with the nuclei of the vagus and glosso-pharyngeal nerves such as is provided by these plexuses.

(*c*) *Spino-vestibular fibres.*—As constituting a separate group of external arcuate fibres, we wish to draw attention to a well-marked bundle of medium-sized fibres which pass outside the thin layer of gray matter which covers the restiform body. These fibres curve round the restiform body and pass ventrally to the descending root of the vestibular nerve as well as towards the plexus just described as lying outside the fasciculus solitarius. Consequently there exists a spino-vestibular system which runs with the most dorsal direct spino-cerebellar fibres.

(2) *Gowers's Tract or the Fasciculus Spino-cerebellaris Ventralis. (Barker.)*

As the researches of Mott have shown that what was known as Gowers's or the ventro-lateral tract is really a

complex of several systems, we have endeavoured to separate these systems, and, as stated above, regard them, at any rate, to be so far determined as to permit of their being enumerated as spino-cerebellar, spino-quadrigeminal, and spino-thalamic fibres, respectively.

It appears to us from examination of the present case that there is also another system included among the fibres of the ventro-lateral tract, and that is a small system of finer fibres which apparently terminate in the nucleus of of the lateral fillet.

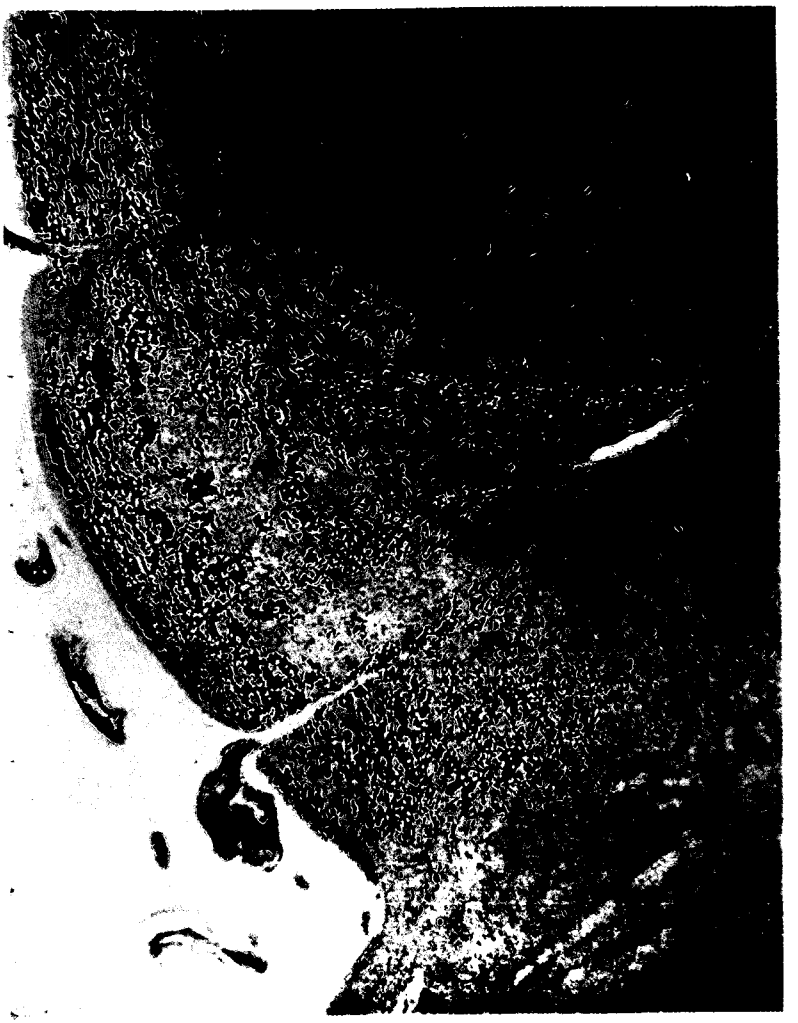
To deal with these points successively and systematically we venture to propose to make use of the expression Gowers's tract only in reference to the system of spino-cerebellar fibres.

We would point out prefatorily that the ventro-lateral field in the spinal cord shows a difference in the size of the fibres; that the outer fibres are rather coarser than the inner division, and further, that this appears to afford a basis for recognising the different tracts from each other. Thus in the higher sections up to (and including) the pulvinar region the coarser fibres pass by way of the superior peduncle to the cerebellum, but the finer fibres can be detected passing as spino-thalamic and as spino-quadrigeminal tracts.

The fibres of Gowers's tract proceeding to the cerebellum do so compactly as a thick bundle just outside the sheet of gray matter (continuous really with the central gray substance), which laps over and round the superior cerebellar peduncle. As the tract lies on the outer surface of the cerebellar peduncle it is intercalated as a layer between two other systems of fibres which are as yet undetermined, and on the highest point it is covered with a thin layer of sub-pial gray substance.

Owing to the fact that in the present case both tracts are completely degenerated, as well as the dorsal spino-cerebellar system, we are not able to add to the present knowledge of the termination of Gowers's tract in the anterior portion of the vermis.

At the same time we wish to draw attention to the following groups of fibres which bear a relation to the ventro-lateral spino-cerebellar system.



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Of these we would note first that fibres leave the tract, enter the velum medullare anterius and pass by way of the frenulum of the posterior corpora quadrigemina to the colliculus of either side.

The second group is much more important and difficult of analysis. Thus it is easy to trace fibres from one tract passing across the roof of the fourth ventricle to the opposite side, where they appear to descend in the sub-ependymal tissue towards the peduncle of the flocculus and the nuclei of the eighth nerve.

We must now discuss previous observations which bear on this group of fibres.

In the rhomboidal area bounded by Deiters's nucleus below, the bundles of the restiform body externally, the lateral wall of the fourth ventricle internally, and the brachium conjunctivum above, there have been for many years observed fibres extending upwards from the region of Deiters's nucleus and the embolus, and to the nucleus tecti in the cerebellum. These fibres are fine fibres, and have been variously described by different observers.

Thus Stilling (p. 175, table xv., *Stilling Disqu. de Struct. et Funct. Cerebri*) spoke of them as being the continuation of the column of the fasciculus cuneatus and the fasciculus gracilis. Bruce pointed out in 1892 that many of them came from the neighbourhood of the superior olive. Edinger, a few years later, showed that they were posteriorly apparently the continuations of various sensory cranial nerves, and he spoke of these bundles as a direct sensory cerebellar tract.

Kölliker describes them (p. 270, *Handbuch der Gewebelehre*) as a strong bundle passing dorsalwards on the mesial side of the restiform body. He traced them to the nucleus tecti, and partly through the embolus and globosus, finding that after decussating they terminated in the nucleus tecti of the opposite side. Thus Kölliker adopts the prevalent view that these fibres are such as leave the neighbourhood of Deiters's nucleus to go towards the cerebellum, and says that another origin to these fibres is not obvious. At the same time he makes the most important observation that he

noticed in a human fœtus of the seventh to the eighth month the terminations of these fibres in the nucleus tecti to be already myelinated, whereas the "bundles of origin" were not, and thus contrasted very strongly with the medullated fibres of the nervus vestibuli and pedunculus cerebelli. This fact seems to us to render it at least improbable that the fibres ascend from Deiters's nucleus and the vestibular nerve into the cerebellum. In speaking of the region of these "bundles of origin," it should be noted that Bruce in 1892 showed the peduncle of the flocculus to spring from the area to which reference has been made. In the present case these fibres are degenerated, and have been described above as being possibly derivatives of Gowers's tract. In remarkable agreement with Kölliker's observation regarding myelination, we may again draw attention to the fact that in our case the lower ends of the fibres, where they are apparently connected with the upper part of Deiters's nucleus are distinctly branching and breaking up.

Our conclusions would be, therefore, that these fibres certainly come at any rate from the neighbourhood of the roof nucleus and pass down the side of the ventricle, to terminate in the upper part of Deiters's nucleus. Whether we are right in regarding them as being the continuation of the antero-lateral tract will have to be tested by subsequent observation, but in support of it may be mentioned that one of us has in the cat traced degenerated fibres of Gowers's tract across the roof of the fourth ventricle to the interval between the brachium conjunctivum and the lateral wall of the ventricle on the opposite side.

These same fibres are described by Miss Sabin in two papers, the most recent of which is that relating to her model of the medulla ("Contributions to the Science of Medicine, Dedicated to Wm. H. Welch, 1900," p. 990). In this connection she draws attention to two bundles of fibres connecting the vestibular nuclei with the cerebellum, which she calls inner and outer group respectively, of the fibres connecting the vestibular area with the cerebellar. Of these the mesial bundle passes into the roof.

The whole question of these fibres is a very difficult one

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to solve, and with reference now to the question of Edinger's views regarding the direct connection of the vestibular nerve with the cerebellum, Ramon y Cajal (*Beitrag zm. Studium der Med. Oblongata, Deutsch. von Bresler*, Leipzig, 1896) includes in his fig. 18 fibres of the vestibular nerve, which, as they pass round the upper end of the spinal trigeminus root, bifurcate, the dorsal limb of the bifurcation running upwards, giving off collaterals to Deiters's nucleus, and terminating in the nucleus tecti. If this arrangement which is found in the mouse is confirmed for other animals and man, then some of these fine fibres must be taken as direct continuations of the vestibular nerve. Such a fact of course would not alter our view of the fibres observed in the present case, because such direct vestibular fibres would necessarily not be degenerated in our case.

Degeneration of the fleece fibres.—The connections of the corpus dentatum by means of the plexus surrounding it and known as the fleece (Stilling) are very important. In the present case numerous very fine degenerated fibres entered the plexus in large numbers on the dorsum of the corpus dentatum, but very few at the lower third of the ventral aspect of the nucleus.

As regards position in respect of the cerebellum as a whole it should be observed that the contributions the fleece receives from the restiform body enter its dorsal portion alone, so far as we were able to ascertain.

(3) *The Fasciculus Spino-tectalis vel Quadrigeminalis.*

This includes those fibres which terminate in the posterior and anterior colliculus respectively.

(*a*) *Fibres to the posterior colliculus.*—We have already stated that fibres leave the spino-cerebellar tract to enter the posterior colliculus by way of its frenulum. The main mass of fibres, however, to the posterior colliculus come towards its nucleus in association with the fibres which we find to end in the nucleus of the lateral fillet, and are running mesially to the latter. The spino-tectal bundles diverge beneath the nucleus of the posterior colliculus, forming a cup or funnel-shaped bed for the oval nucleus.

This description of the fibres beneath the ovoid nuclear centre of the posterior colliculus has been given by various anatomists for the fibres of the lateral fillet, and the spinal fibres are in the normal case not distinguishable from those of the lateral fillet, but are necessarily more caudal. In fact, the account given by Kölliker of the normal lateral fillet is exactly applicable to our spino-tectal (posterior) system.

(*b*) *Fibres to anterior colliculus.*—The termination of the spino-tectal system in the anterior corpus quadrigeminum is very definite. The fibres are at the most distal plane of the colliculus arranged in an oval bundle situated in the outer part of the deep medullary stratum, and therefore close beneath the posterior brachium. From this point the fibres ascending parallel to the longitudinal axis of the mesencephalon give off collaterals or turn off directly to run in the commissure between the corpora and in the deep medullary stratum. These give off collaterals at right angles, which enter the upper gray layers of the homolateral colliculus. Others pass across the middle line and enter the contralateral colliculus.

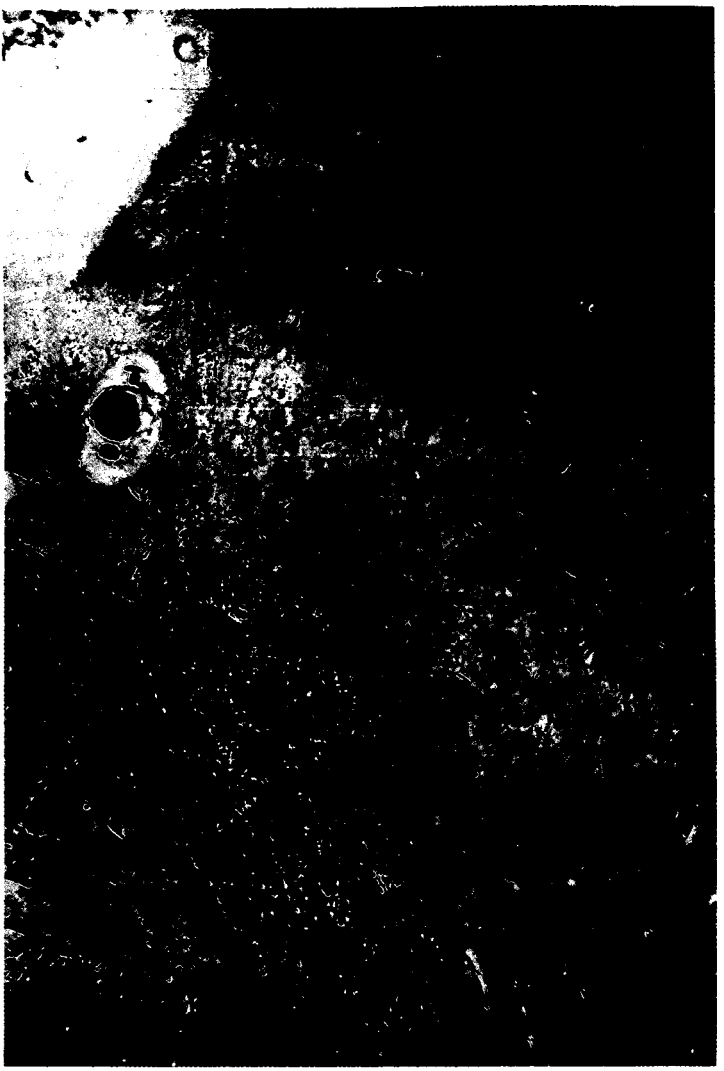
The gray layers of the corpus quadrigeminum thus receive the spinal fibres as follows: Those which end homolaterally pass into the outer part of the gray layers, and those which end contralaterally enter the inner portions of the gray layers.

(4) *The Fasciculus Spino-thalamicus.*

After the ascending ventro-lateral tract has given off its contributions to the cerebellum and corpora quadrigemina as just detailed, the remnant of the fibres pass on to enter the thalamus.

In doing this the fibres spread out so that the bundle presents in transverse section a V-shaped figure. These fibres enter the pulvinar, and constitute, doubtless, a tract of considerable phylogenetic importance.

A few words may be added concerning degeneration in tracts other than those described.



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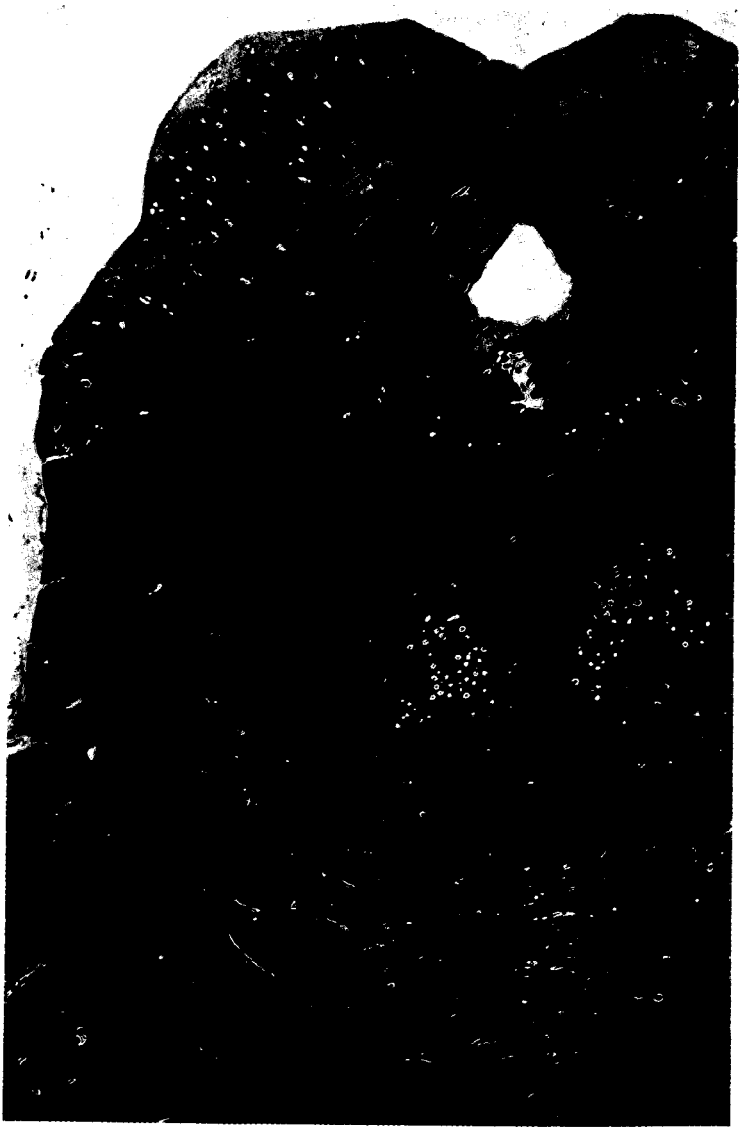

(1) *Pyramidal system.*—A general and equal degeneration of coarse fibres was present in both pyramidal tracts, and in the spinal cord was spread over both the crossed tract and also the direct tract. The question whether this degeneration is possibly an ascending one has been raised by Dr. Purves Stewart in his case of injury of the cervical cord. In our case, however, sections across the parietal lobe showed not only extensive degeneration of large fibres descending (?) from the cortex, but also numerous medium-sized fibres passing into and across the corpus callosum.

Although no gross lesion of the cortex was discoverable in the osmic stained sections, we think that the above facts show that, probably as a result of concussion, the pyramidal corpuscles in the cortex suffered damage, and that their axones had degenerated in consequence. The patient in the present case undoubtedly received a severe shock, and, as mentioned above, suffered from a large scalp wound in the occipital region.

Pending further observations on this point it would perhaps be safer to regard the coarse degeneration of the pyramidal system as being of cortical origin and descending character.

Posterior longitudinal bundle system.—A few coarse fibres were traceable throughout the whole course of the posterior longitudinal bundle system. Thus in the anterior columns of the cord these fibres lay in front of the anterior commissure, and mingled ventrally with those of the direct pyramidal tract, occupying the mesial portion of the column. Higher up, at the level of the commencing decussatio lemniscorum, these same fibres lay close outside the fillet fibres. In their course up the medulla they kept close to the raphe, and finally in the mesencephalon formed the mesial border of the posterior longitudinal bundle. They began to disappear opposite the anterior corpus quadrigeminum, and at the commencement of the commissura mollis were reduced to a few units, appearing to end in the so-called nucleus of the posterior longitudinal bundle.

We have described these fibres as ascending in character because of their mode of termination and gradual disappearance headwards.

The "accessory fillet" (Schlesinger).—This is a tract which is in the main composed of medium-sized fibres. In the upper sections the fibres were compactly arranged and formed a tract, the fibres of which, passing downwards and outwards, became lost externally in the lateral fillet, and mesially in the tegmentum.

The tract first appears in the plane of the pulvinar. We believe with Redlich and Hoche that it is a downward efferent path of the pyramidal system, from which it obviously arises while traversing the pons.

The dorso-olivary fibres (von Solder).—At the commencement of the hinder pole of the olive von Solder's tract was visible as numerous scattered, fine, degenerate fibres and a few coarse ones, which latter were continuous with those from the anterior columns left after the decussation of the pyramids is established. The fine fibres are marked all along the dorsum of the olive, and limited, dorsally, partly by the ganglion cells of the formatio reticularis, while laterally they were continuous with the medium-sized fibres of the antero-lateral tract. Some fibres were scattered around the dorsal accessory olive, reaching outwards ventrally to the ventral nucleus of the funiculus lateralis and coursed round the surface of the bulb, just outside the capsule of the outer end of the inferior olive.

Some of the most mesial fibres passed into the inner side of the inferior olive.

As the fibres were traced upwards they almost all passed above the outer part of the fillet and entered the tegmentum. In this way they passed straight up to the thalamus and terminated by subdividing minutely in the ventral nucleus of the thalamus. von Solder traced the same fibres as far as the plane of the corpus geniculatum mesiale.

Posterior column system.—In the cord Goll's columns were equally degenerated on the two sides, the degeneration reaching only about three-fifths of the way along the median fissure. On the one side Burdach's column is affected in its median fourth, and for only two-thirds of its length posteriorly. The degenerated fibres could be traced upwards to the level of the pyramidal decussation, the nucleus gracilis

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being there hardly marked, and at the same point the degenerated fibres became much finer.

At the lowest level of the bulb, where the corp. restiforme is distinctly formed, fine degenerated fibres, continuous with those of the posterior columns, form a delicate area of degeneration at the inner side of the restiform body, being separated from the degenerated spinal fibres by olivary fibres. These fine fibres join a fine meshwork of fibres in the dorsal part of the spino-vestibular root and nucleus, and appear to lose themselves in the gray matter just above the tuberculum acusticum, becoming finally lost beneath the ependyma as high up as the level of Deiters's nucleus.

The nuclei of the posterior columns show extensive degeneration, and from them a few fine degenerate fibres pass down as internal arcuate fibres into the fillet of each side. Similar fibres were first observed by Purves Stewart, but they disappear very soon from the fillet, and resemble fine collaterals rather than direct fibres.

Degeneration of the stria medullaris.—The fibres of the stria entering the ganglion habenulæ were in this instance degenerated, as also some coarse fibres in the posterior commissure. We were, however, unable to determine the cause or relations of these degenerations.

NOTE.—I desire to add to the above account the fact that the heavy labour of preparing the large series of preparations in the above case was executed by Dr. Thiele. —V. H.