derived principally from the posterior roots of the Nn. lumbales and Nn. sacrales. They seem to correspond to the "fibres of intermediate length" of P. Marie's classification. His "long fibres" belong to the direct ascending path of the posterior funiculus, and his "short fibres" to the path to the posterior horn. Against the view that the path to Clark's nucleus corresponds to the third fœtal system of Trepinski, it might be urged that Flechsig states that medullation of these fibres begins in fœtuses 19–20 cm. long. Redlich has, however, expressed the opinion that the majority of fibres going to Clark's nucleus become medullated at a much later period—a view which my studies tend to corroborate. It is of course quite thinkable that the path to Clark's nucleus may later have to be subdivided into a number of different fibre systems, corresponding to different periods of medullation and perhaps to differences in functional significance. The individual fibres running in to end in the nucleus dorsalis are of small calibre, and each fibre breaks up into an end arborization which comes into relation with several cells of the nucleus. As to their function, the findings in cases of hereditary ataxia above referred to indicate that these fibres carry the impulses which, when transmitted through the direct cerebellar tract to the cerebellum, prevent that coarse variety of ataxia so pronounced in the individuals affected in the family described by Dr. Sanger-Brown. They can be concerned, however, only with impulses derived from the lower extremities and the trunk.

The *path to the posterior horn* includes the fibres which ascend in the posterior horn itself, the fibres which run in the posterior funiculus and turn in to end in the posterior horn, and the terminals and collaterals of the fibres of Lissauer's fasciculus. The majority of them appear to be fibres which end a short distance above the level of the posterior root, to which they belong. As they become medullated at very different periods, they probably consist of a series of embryological fibre systems. The majority of the fibres are small; they end in telodendrions about the cells of the substantia gelatinosa, the cells of the zonal layer, and the cells of Waldeyer's nucleus of the posterior horn. It is believed that the impulses concerned in tactile, painful, and thermic sensations enter the cord through these fibres, but the evidence has been gained *per exclusionem* rather than in any other way.

The *reflex path to the anterior horn* consists chiefly of collaterals which come off from the posterior root fibres and run forward in S-shaped curves, partly through the medial portion of the substantia gelatinosa, partly through the interval between the substantia gelatinosa and the nucleus dorsalis in regions of the cord in which the latter is present. They end in telodendrions about the anterior horn cells. It seems probable that each ascending limb of bifurcation of a posterior root fibre may give off several such reflex collaterals; others doubtless come off from the descending limb of bifurcation, and some from the stem fibres themselves before the bifurcation. The majority of the reflex collaterals go to the anterior horn of the same side of the cord, but some of them pass through the posterior intracentral commissure to reach the anterior horn of the opposite side. These reflex collaterals begin to be medullated in fœtuses 28 cm. long, but the medullation continues through several months. The fibres are of fine calibre; on their integrity depend the superficial and deep reflexes. It seems very probable that the main fibres which go to form the direct ascending path of the posterior funiculus give off the reflex collaterals—that is to say, the same neurones which serve to conduct impulses to the cerebral centres which are concerned in consciousness are utilized also to carry the impulses which set free reflexes.

A word must be said about the *descending limbs of bifurcation of the posterior root fibres*. In the case of secondary degeneration, studied by Dejerine and Thomas, in the cervical region the descending fibres of a posterior root extended over three segments in the form of an anteroposterior stripe situated in the lateral part of the fasciculus cuneatus. In Schaffer's case of lesion of the fifth lumbar root the degeneration was slight, being represented by an anteroposterior stripe extending from the posterior commissure to the posterior surface of the funiculus, and running parallel to the posterior median septum. The comma-shaped degeneration met with in the posterior funiculus after transverse lesion of the cord appears to be due to degeneration of endogenous fibres (which I have designated as the fasciculus posterior proprius) rather than to descending fibres of the posterior root.

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2. *Central Sensory Neurone Systems* (Centripetal Neurone Systems of the Second Order).—We have seen that the central axones of the peripheral neurone systems (centripetal neurone systems of the first order) end in various masses of the gray matter of the spinal cord and medulla—the so-called terminal nuclei of the peripheral sensory spinal nerves. Among these terminal nuclei we have mentioned the nucleus funiculi gracilis and nucleus funiculi cuneati of the medulla oblongata, the nucleus dorsalis (Clarkii) on each side, and the gray matter of the posterior horn or columna grisea posterior. In these terminal nuclei are situated the cell bodies and dendrites of neurones of the second order, the axones of which carry the impulses farther.

The medullated fibres which correspond to the axones coming from the nuclei of the posterior funiculi in the medulla oblongata go to form, after decussation, the medial lemniscus (cf. article *Brain, Histology of*). It will not be further discussed here.

The medullated axones coming from the cell bodies situated in the nucleus dorsalis (Clarkii) form a very important fibre system, the so-called "direct cerebellar tract," or Flechsig's bundle. It is sometimes described as the fasciculus cerebellospinalis, but I prefer to designate it the *fasciculus spinocerebellaris dorsolateralis.* This fibre bundle, recognized by Foville, Türck, and Meynert, was first exactly described by Flechsig. The axones come off from the cells in Clarke's nucleus, turn horizontally lateralward in curves to reach the posterolateral periphery of the funiculus lateralis, and then turn in the longitudinal direction to run the whole length of the cord and pass through the corpus restiforme to end in the cerebellum. The fibres receive their myeline sheaths at about the sixth or seventh month of fœtal life. The fibres are of very large calibre, measuring from 3 to 10 μ in diameter, the majority measuring from 6 to 8 μ. They stand close together and are often sharply recognizable in normal Weigert preparations as a distinct compact mass, which contrasts with the neighboring pyramidal bundles.

As the nucleus dorsalis is represented below the thoracic cord only by the sacral nucleus of Stilling, only a few fibres corresponding to the direct cerebellar tract are to be found below the twelfth thoracic segment (Fig. 4407).

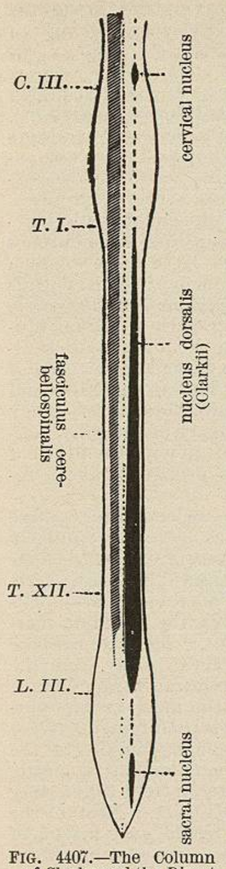

FIG. 4407.—The Column of Clarke and the Direct Cerebellar Tract. The situation and volume of the column of Clarke are shown as a heavy black band on the right; those of the direct cerebellar tract are represented by a striated black band on the left. (From Poirier et Charpy, "Traité d'anatomie humaine," t. iii., 2 ed., Paris, 1901, p. 206, Fig. 146.)

The bundle of fibres occupies a comma-shaped field in the lower thoracic cord corresponding to the third and fourth fifths of the periphery of the lateral funiculus, counting from the front. In the upper thoracic cord it may displace the lateral pyramidal tract from the periphery and extend backward as far as Lissauer's fasciculus. In the cervical region it occupies the whole dorsal half of the periphery of the lateral funiculus except at the level of N. cervicalis II., where the posterior seventh of the periphery is occupied by the lateral pyramidal tract. The medial portion of the area of the tract throughout its whole extent is overlapped slightly by the area of the lateral pyramidal tract, the fine fibres of the latter being mixed with the coarser fibres of the former. On the whole, however, the limitation as seen under a low power is tolerably sharp.

The area of the tract increases steadily in the cross-sections, as the cord is ascended. There has been some dispute as to whether all of the fibres of the tract go to the cerebellum, or whether some end at different levels in the gray matter of the cord; the weight of opinion, at present, is in favor of the former view. The fibres ultimately terminate in the vermis superior (Flechsig, von Monakow, Mott). As has already been pointed out, the tract always undergoes ascending secondary degeneration in transverse lesions of the thoracic cord. I have called attention in another place to the marked liability of this tract to injury in acute cerebrospinal meningitis, owing doubtless to its exposed position on the surface of the cord ("On Certain Changes in the Cells of the Ventral Horns and of the Nucleus Dorsalis [Clarkii] in Epidemic Cerebrospinal Meningitis," *Brit. Med. Jour.*, London, 1897, ii., pp. 1839–41). Studies in tabes and in hereditary ataxia make it seem probable that the neurone system of the second order, to which the fibres of this tract belong, conducts to the cerebellum the group of centripetal impulses concerned in the automatic regulation by the cerebellum of the body equilibrium.

The medullated fibres which correspond to the axones coming from the cells of the gray matter of the posterior horn, give rise to several fibre systems, among which may be mentioned the superficial anterolateral fasciculus of Gowers, the fasciculus anterior proprius, the fasciculus lateralis proprius, and the fasciculus posterior proprius.

The *fasciculus anterolateralis superficialis* (*Gowersi*) is also, in the main, an ascending tract from the spinal cord to the cerebellum. I have suggested that this main part of it be called, therefore, the *fasciculus spinocerebellaris ventrolateralis.* Developmentally, it is a part of Flechsig's anterior mixed zone of the lateral funiculus. The exact position of the cells in the gray matter, which give off these axones, is not yet known. It seems probable that they are in the posterior horn, or in the columna intermedia between the posterior horn and the anterior horn, and it is certain that while some of the cells of origin are in the gray matter of the same side, many of them are in the gray matter of the opposite side of the cord, the crossing taking place through the commissura anterior alba. Hence the neurones, to which the fibres of Gowers' tract belong, are partly tautomeric, partly heteromeric neurones. The fibres become medullated at the beginning of the eighth fœtal month (von Bechterew). The calibre of the fibres varies a good deal; some of them are coarse, others fine.

The tract begins in the lumbar portion of the spinal cord, where it lies in the middle of the periphery of the lateral funiculus, occupying about one-seventh of that periphery. Higher up, as the area of the tract increases in size, the additions are made chiefly anteriorly. In the cervical and upper thoracic cord the area occupied by the tract extends from the anterior extremity of the area of Flechsig's direct cerebellar tract to near the sulcus lateralis anterior. The shape of the area as seen in cross-section varies a good deal in different human cases. The area is not sharply limited, either medialward or dorsalward, as it is overlapped slightly by the area of the direct cerebellar tract of Flechsig and by other fibre systems of the fasciculus lateralis. Mixed up with the fibres of Gowers' tract, which are ascending, are some fibres of descending tracts, as secondary degenerations show.

There is a good deal of evidence in support of the view that not all of the fibres of Gowers' tract reach supraspinal terminations, many of them ending in the gray matter of the cord on the way up. It is possible that some of them pass dorsalward to run farther upward in the direct cerebellar tract of Flechsig. The course of Gowers' tract through the medulla oblongata and pons has been followed by Patrick and by Hoche. It goes cerebralward as far as the colliculus inferior and then runs backward through the velum medullare anterius, along with the fibres of the brachium conjunctivum, to end in the vermis superior, partly on the same side, partly on the opposite side (Fig. 4408).

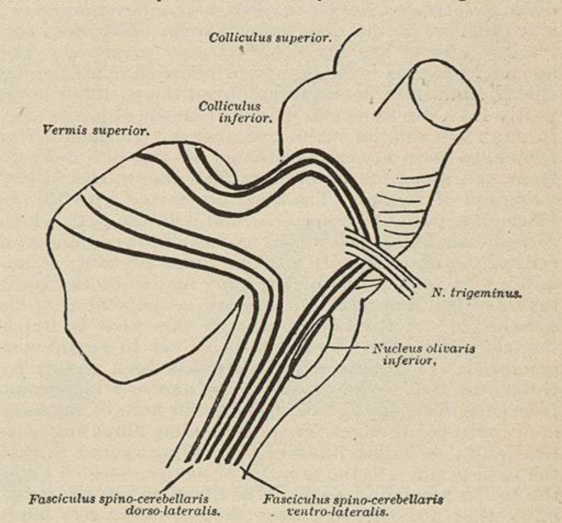

FIG. 4408.—Diagrammatic Representation of the Course of the Fibres of the Two Principal Tracts Ascending from the Spinal Cord to the Cerebellum. (After F. W. Mott, *Brain*, Lond., vol. xv., 1892, p. 219, Fig. 1.) The fasciculus spinocerebellaris ventrolateralis Gowersi and the fasciculus spinocerebellaris dorsolateralis are united in the cord and in the lower part of the medulla. The latter passes into the corpus restiforme and terminates in the dorsal portion of the superior vermis. The former remains ventrally situated until it reaches the level of the N. trigeminus; passing beyond this it forms a loop backward to reach the dorso-lateral surface of the brachium conjunctivum. The fibres then course backward and sweep round into the anterior portion of the superior vermis.

In addition to the main portion of Gowers' tract, which represents a spinocerebellar neurone system by way of the brachium conjunctivum (systema neuronicum spinocerebellare ventrolaterale conjunctivale), there are in the tract fibres which end in the superior colliculus of the corpora quadrigemina (systema neuronicum spinoquadrigeminum superius), fibres which end in the thalamus (systema neuronicum spinothalamicum), and fibres which go to the cerebellum by way of the corpus restiforme (systema neuronicum spinocerebellare ventrolaterale restiformale). If Rossolimo's observations should be confirmed, there are also, in Gowers' tract, fibres which terminate in the inferior colliculi, in the substantia nigra, and in the nucleus lentiformis.

As to the function of Gowers' tract there is much dispute. Gowers himself thought that the tract might conduct pain impulses. It seems more probable, however, that the function of this tract is similar to that of the direct cerebellar tract of Flechsig.

The *fasciculus anterior proprius, fasciculus lateralis proprius*, and *fasciculus posterior proprius* may next be discussed. Secondary degenerations show that these fasciculi are made up partly of ascending fibres, partly of descending fibres; partly of fibres coming from cells of the gray matter of the same side of the cord, partly of fibres coming from cells of the gray matter of the opposite side of the cord. Of these three fasciculi, the fasciculus lateralis proprius is by far the most voluminous. The fasciculi proprii become medullated early in fœtal life and are of great interest to the clinician, since in them are to be sought, as far as we can now see, the paths which conduct the impulses concerned in the sensations of touch, temperature, and pain.

The centripetal neurones of the second order, whose axones run in the fasciculus anterior proprius, may be divided into two sets: (1) those of ascending axones (*ascending centripetal path of the fasciculus anterior proprius*), and (2) those of the descending axones (*descending centripetal path of the fasciculus anterior proprius*). The ascending path is made up of medullated axones coming chiefly from the cells in the interior of the posterior horn, partly from the same side, partly from the opposite side, through the anterior white commissure. In the anterior funiculus these fibres are situated at the periphery in front and along the anterior median fissure (*zone sulcomarginale* of Marie). The fibres are mixed up with the descending path of Loewenthal, and with the path which corresponds to the medullated axones of the commissural cells of the anterior horn. These fibres probably terminate at various levels of the gray matter of the cord, sending their impulses on through centripetal neurone systems of the third order, though this view is hypothetical. We have but few facts as yet to record concerning it. The descending path has been shown by Golgi's method to be made up of axones which come from cells in the interior of the posterior horn of the same or of the opposite side. These descending fibres are practically all descending limbs of bifurcating axones, so that the path pertains to the same set of neurones which gives rise to the ascending path. The fibres end in all probability after a shorter or longer (though never very long) course in the gray matter of the anterior horn. Whether they enter into conduction relation chiefly with the motor cells or with the commissural cells of the anterior horn is not known, but in either case they would participate in the setting free of the more complex spinal reflexes.

The centripetal neurones of the second order, whose axones run in the fasciculus lateralis proprius, may also be divided into two sets: (1) those with ascending axones (*ascending centripetal path of the fasiculus lateralis proprius*); and (2) those with descending axones (*descending centripetal path of the fasciculus lateralis proprius*). The ascending path corresponds to the medullated axones of the marginal cells of the posterior horn and of the nerve cells in the caput of the posterior horn, partly of the same side, partly through the posterior intracentral commissure of the opposite side. The fibres of this path run partly in the anterior mixed zone among the fibres of Gowers' tract and of Marchi's descending cerebello-spinal path, partly in the lateral limiting layer of the gray matter. These fibres are very fine in calibre. Most of them are short, extending over only one, two, or three segments, after which they run in to end in the gray matter of the cord, where they come into conduction relation with centripetal neurones of the next higher order (columna intermedia, columna intermediolateralis). It is this path, made up of a whole series of neurones with relatively short axones superimposed upon one another, that has to do, in all probability, with the conduction of tactile, painful, and thermic sensory impulses. Since tactile sensations developed presumably phylogenetically, it is perhaps not surprising that the neurones forming the path for them should have axones which extend over only one to three metameres. This path is designated by Ziehen the "*aufsteigendes Binnenbahnsystem des Seitenstrangs.*" The descending path of the fasciculus lateralis proprius consists of the medullated descending limbs of bifurcation of those axones from the cells of the posterior horn which go to the lateral funiculus and bifurcate into ascending and descending branches. They run chiefly in the lateral limiting layer of the gray matter, though some of them are mixed up with the fibres of the lateral pyramidal tract. They probably have a reflex function.

The centripetal neurones of the second order, whose axones go to the posterior funiculus, give rise similarly to *an ascending and a descending centripetal path in the fasciculus posterior proprius*. The ascending path corresponds to the medullated axones of all three kinds of cells in the posterior horn—Gierke's cells, the zonal or marginal cells, and the cells of the caput. The axones come partly from the same side of the cord, partly from the opposite side through the posterior intracentral commissure. They run longitudinally in the most ventral portion of the posterior funiculus. This path remains intact in tabes dorsalis. It is the endogenous bundle of the posterior funiculus and does not degenerate after posterior root lesions, though some posterior root fibres may be mixed up with the fibres of this tract. Most of the fibres are short, turning in to end in the gray matter of adjacent levels; among them, however, are some fibres which are much longer. Their function is unknown; it may perhaps be assumed that they have to do with the more complex reflexes. The descending path in the fasciculus posterior proprius has been much better studied. Being endogenous, it often remains intact in tabes; it may be found degenerated in cases of syringomyelia. The tract is made up of fibres from the posterior horn cells, and corresponds chiefly to the descending limbs of fibres which undergo T-shaped bifurcation in the posterior funiculus. These fibres correspond to the comma-shaped area of degeneration of the upper part of the cord, to the "oval field" of Flechsig lower down, and still lower to the "triangle" of Gombault and Philippe. This tract, in all probability, corresponds to the "descending septomarginal tract" of Bruce and Muir, and to the *dorsomediales Sacralbündel* of Obersteiner. It must not be forgotten that circumscribed as this bundle is, there are always some fibres derived from the posterior roots mixed with its endogenous fibres. The function of the descending tract in the posterior funiculus is unknown, though Mann has suggested that it has something to do with the innervation of the Mm. intercostales.

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B. Centrifugal Neurone Systems in the Spinal Cord. (Central Motor Neurones.)

Under this heading are to be considered the neurone systems, the axones of which enter into conduction relations with the cell bodies and dendrites of the lower motor neurones of the anterior horns. The central motor neurones, by means of this conduction relation, which their axones establish with the lower motor neurones, help to form the general motor conduction path from the higher centres of the brain to the muscles of the body. The lower motor neurones have cell bodies and dendrites in the gray matter of the spinal cord, but only the proximal portions of their axones are in the cord itself; the main portions of the axones lie peripheral to the cord, forming the anterior roots and the motor portions of the peripheral nerves; the axones finally terminate in motor end-plates (telodendrions) on the muscle fibres. These lower motor neurones are thrown under the direct influence of the peripheral sensory neurones by means of the reflex collaterals from the posterior root fibres. They are less directly under the influence of the peripheral sensory neurones by means of intercalated associative central neurones in the cord, the axones of which help to make up the ascending and descending fibre systems of the fasciculi proprii. They are still more remotely under the influence of the peripheral centripetal neurones by means of the conduction relations which are established between the central sensory neurones (the axones of which terminate in higher centres) and the upper motor neurones of the general motor conduction path. It is these upper motor neurones which must now be considered.

Cerebrospinal Motor Neurones (Neurones the Axones of which Make up the Fibres of the Pyramidal Tracts).—These are the neurones the cell bodies and dendrites of which are situated in the motor area of the cerebral cortex, and the axones of which run downward to terminate about the motor cells of the anterior horns. These neurones mediate the conscious movement impulses sent out from the brain voluntarily to the spinal cord (and thus toward the muscles). The axones leaving the cortex run through the centrum semiovale of the hemisphere, help to form the corona radiata of the capsula interna and pass through the anterior two-thirds of the posterior limb of the capsule. In the capsula interna the fibres governing the movements of the upper extremity are in front of the fibres controlling the movements of the lower extremity. Below the internal capsule the

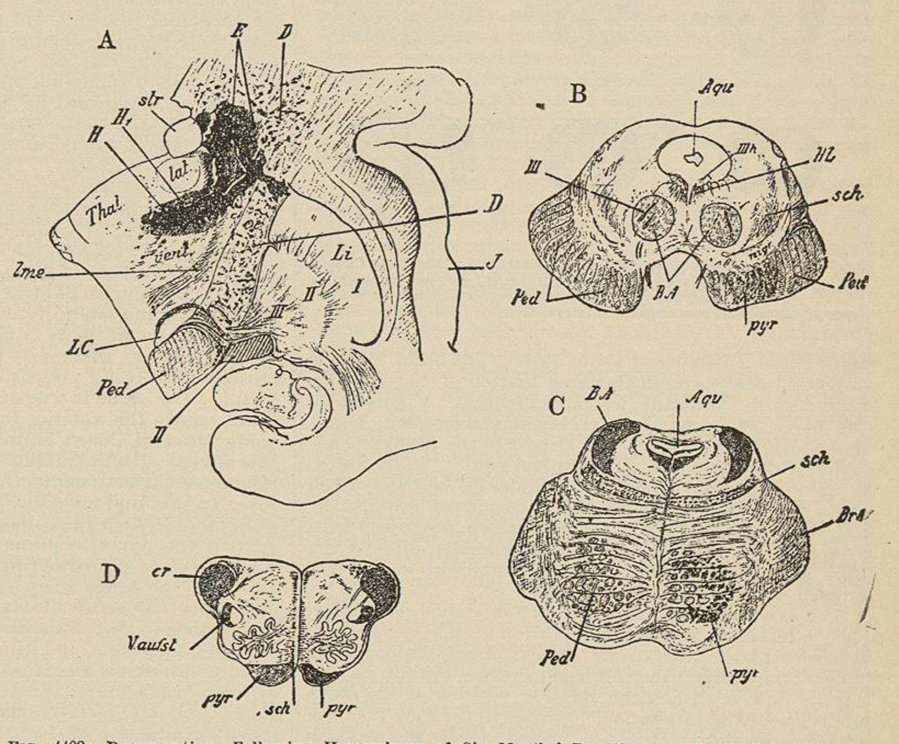

FIG. 4409.—Degeneration, Following Hemorrhage of Six Months' Duration, in the Nucleus Lateralis Thalami and in the Lenticulo-optic Portion of the Capsula Interna. (After C. von Monakow, "Gehirnpathologie," Wien, 1897, Figs. 171–175.) *A*, Oblique horizontal section through the anterior part of the nucleus hypothalamicus, corpus Luysi; *H*, cystic nodule filled with transformed blood; *Hl*, *E*, pericystic softening; *ci*, capsula interna; *D*, secondary degeneration in the capsula interna; the pyramidal tract is interrupted and totally degenerated; *J*, insula; *LC*, nucleus hypothalamicus; *Ped*, pedunculus cerebri; *II*, tractus opticus; *Li*, nucleus lentiformis; *str*, corpus striatum; *lat*, nucleus lateralis thalami; *vent*, nucleus ventralis thalami; *lme*, lamina medullaris. *B*, *C*, *D*, fronto-horizontal; *B*, level of the colliculus superior and of the pedunculus cerebri; *C*, middle of pons; *D*, medulla oblongata. *Aqu*, aquæductus cerebri; *III*, nervus oculomotorius; *III K*, nucleus nervi oculomotorii; *sch*, lemniscus medialis; *HL*, fasciculus longitudinalis medialis; *B A*, brachium conjunctivum; *Br A*, brachium pontis; *Ped*, pedunculus cerebri; *pyr*, pyramidal tract degenerated on the right side; *cr*, corpus restiforme; *V.aufst*, tractus spinalis nervi trigemini.

fibres run through the base of the cerebral peduncle at about its middle, plunge through the basilar part of the pons, helping to form the longitudinal fasciculi of that region, to reach the medulla oblongata, where they form the well-known fasciculi pyramidales, which on each side correspond to the pyramis medullæ oblongatæ, which can be seen from the surface. In the lower part of the medulla oblongata the fibres undergo a partial decussation, the so-called decussatio pyramidum, which takes place

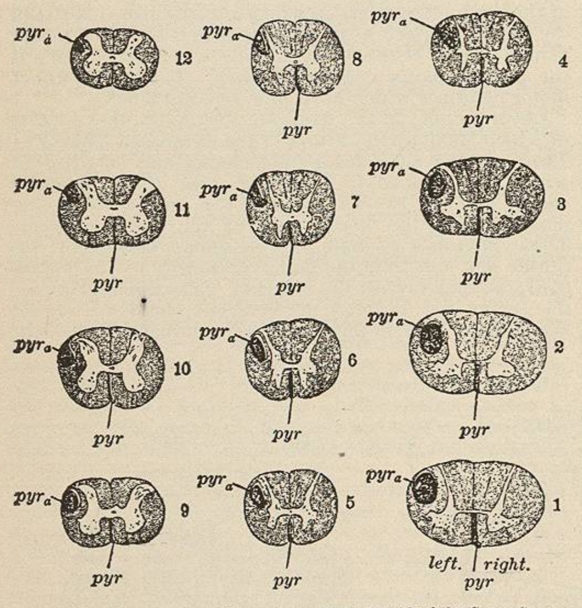

FIG. 4410.—Degenerated Fibres in the Spinal Cord of the Same Case as that shown in (Fig. 4409). 1-3, pars cervicalis; 4-8, pars thoracalis; 9-12, pars lumbosacralis; *pyr*, fasciculus cerebrospinalis ventralis; *pyra*, fasciculus cerebrospinalis lateralis.

throughout a distance of about 1 cm. The fibres, in their crossing, pass through the gray matter of the anterior horn into the opposite lateral funiculus. A portion of the fibres of each pyramid remains uncrossed, going down chiefly as an uncrossed bundle in the funiculus anterior of the same side of the spinal cord. A few fibres, however, pass downward in the funiculus lateralis of the same side. The fasciculus cerebrospinalis anterior or anterior pyramidal tract is therefore an uncrossed fibre system, while the fasciculus cerebrospinalis lateralis is a fibre system chiefly crossed, but containing a few uncrossed fibres (Figs. 4409 and 4410).

The lateral pyramidal tract, or fasciculus cerebrospinalis lateralis in the cervical portion of the spinal cord, occupies a large area in the posteromedial region of the lateral funiculus. Its volume decreases rapidly as the cord is descended and the relative position of the fibres undergoes some alteration. Owing to the fact that the direct cerebellar tract is not present below the thoracic cord, the lateral pyramidal tract in the lumbosacral region comes to lie adjacent to the periphery of the cord.

The decrease in volume as the cord is descended is owing partly to a progressive diminution in the calibre of the fibres, but chiefly to the fact that constituent fibres of the bundle leave it at each segment to turn into the gray matter of the anterior horn, to end there. More fibres turn in to end in the segments which correspond to the cervical and lumbar enlargements than elsewhere in the cord, since it is over the muscles innervated by these segments that the cerebrum exercises the most refined control (muscles of the upper and lower extremities).

The fibres of the anterior pyramidal tract (fasciculus cerebrospinalis anterior) decrease also in number as the cord is descended, the loss in it being very great in the region of the intumescentia cervicalis. The fasciculus is entirely exhausted on its way through the thoracic cord, none of its fibres reaching as far as the lumbar cord. The majority of the axones of the anterior pyramidal tract run in to terminate in the anterior horn of the same side, but a few of them pass through the commissura anterior alba to end in the anterior horn of the opposite side.

The fibre systems of the pyramidal tracts are exquisitely localizable by the embryological method of Flechsig, since at birth practically all the fibres of the spinal cord, with the exception of the pyramidal tracts and the little tract in the upper cervical region known as Helweg's path, are fully medullated. This is an interesting fact, for the medullated axones of the lower motor neurones are among the first of all the nerve fibres of the body to be medullated. Accordingly the corticomuscular conduction path in its lower part (anterior roots and motor nerves) is medullated and presumably ready for function long before its upper part (pyramidal tracts), the explanation being that the lower part of the corticomuscular conduction path also subserves the function of the motor limb of the direct reflex conduction paths.

The embryological method throws much light upon the variations in decussation which occur in the lower part of the medulla oblongata. The lateral pyramidal tracts are never entirely absent. They usually make up from eighty to ninety per cent. of the total volume of the cerebrospinal fasciculi, but the proportion varies a great deal, more fibres crossing in one case than in another. In rare cases as few as ten per cent. of the fibres go over into the lateral funiculus, the remaining ninety per cent. continuing downward in the anterior funiculus. In other rare instances the whole pyramidal tract goes over into the lateral funiculus and the fasciculus cerebrospinalis anterior is absent. There is sometimes asymmetry on the two sides, the asymmetry more often affecting the anterior pyramidal tract than the lateral tract, though it may affect both. Usually the asymmetry is due rather to a unilateral excess in the decussation than to an excess in the total number of fibres. Occasionally a part of the fibres of the pyramidal tract descends at the junction of the anterior and lateral funiculi.

The pyramidal tracts in monkeys appear to have similar relations to those met with in man, uncrossed and crossed fibres being present in the lateral and anterior funiculi. The same is true of the dog, though only a few fibres run in the anterior funiculus, the pyramidal tract being situated almost entirely in the lateral funiculus in this animal. In the rabbit the pyramidal tract is nearly all a crossed tract running in the opposite lateral funiculus. In rats and mice the pyramidal fibres form a definite bundle which runs almost exclusively in the anterior part of the opposite posterior funiculus. Even marsupials have a well-marked pyramidal decussation, the majority of the fibres descending in the opposite lateral funiculus. Whether birds possess a pyramidal tract corresponding to that of mammals or not, is still in dispute. Reptiles, amphibia, and fish seem to be devoid of pyramidal tracts—that is, of cortico-spinal motor tracts—though all vertebrates may have a path for throwing the spinal movements under the domain of consciousness.

An examination of the fibres of the pyramidal tracts in the spinal cord shows that a majority of the fibres are fine in calibre, though there are some coarser fibres mixed among the finer fibres. The large fibres of the direct cerebellar tract stand out in marked contrast with the fine fibres of the pyramidal tract. The lateral pyramidal tract (*fasciculus cerebrospinalis lateralis*) in human beings lies always in the posterior part of the lateral funiculus. It rarely goes farther forward than the continuation of a line drawn through the two lateral horns (Flechsig). The relation to the periphery varies in different parts of the cord. At the level of the first cervical segment the area of the pyramidal tract nowhere reaches the periphery. At the level of the second and third cervical segments the area touches the periphery just lateralward from Lissauer's fasciculus. In the cervical enlargement the tract is again separated from the periphery. As the thoracic

cord is descended the fasciculus approaches the periphery gradually, the posterior part reaching the surface first, the anterior part last. Below the thoracic cord, the whole lateral margin of the tract lies upon the periphery, there being no direct cerebellar tract below that level. The shape of the cross-section of the tract varies as the cord is descended. The lateral pyramidal tract usually disappears at the level of the Nn. sacrales III. and IV.

The anterior pyramidal tract (*fasciculus cerebrospinalis anterior*) is situated in the medial portion of the funiculus anterior. As was pointed out above, it varies greatly in size, and, corresponding to this variation, it sometimes occupies the whole medial margin of the anterior funiculus; in other cases only the middle or posterior portion of the same. It usually terminates below in the middle of the thoracic cord, but may end as high up as the intumescentia cervicalis, or extend as low down as the middle of the intumescentia lumbalis; in one instance even as far as the conus medullaris.

The fibres of the pyramidal tract end by running into the gray matter, not in bundles but usually as individual fibres, or small groups of fibres. Studies by Golgi's method make it seem probable that the terminals come into relation with the cells of the anterior horn, though their exact pericellular relations are yet to be worked out. Von Monakow believes that at least a part of the fibres end in the formatio reticularis, and that dendraxones (Golgi cells of type II.) are intercalated between the terminals of the pyramidal tract fibres and the cell bodies of the lower motor neurones. Rothmann maintains that the fibres of the pyramidal tract very quickly lose their myeline sheaths on entering the anterior horn, and suggests that this accounts for the difficulty in following them to their termination by Marchi's method in experimental degenerations. Campbell has followed terminals of the pyramidal tract into the gray matter, however, by the method of Marchi. The assumption that many of the fibres of the lateral pyramidal tract do not end in the anterior horn of the same side, but pass through the commissure to end in the gray matter of the opposite side (that is, that the fibres recross), has no strong support. As has been said, at least the majority of the fibres of the anterior pyramidal tract end in the anterior horn of the same side, though some appear to pass through the commissura anterior alba to end in the anterior horn of the opposite side (Hoche).

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C. Spinopetal Neurone Systems Other than those whose Axones Belong to the Pyramidal Tracts.

Of late years a great deal of attention has been paid to the centrifugal spinopetal paths other than those corresponding to the pyramidal tracts. Among these there have been described: (1) a neurone system from the thalamus to the cord (thalamospinal neurone system); (2) a rubrospinal neurone system with cell bodies in the red nucleus, the medullated axones of which go to the lateral funiculus of the opposite side of the cord (von Monakow's bundle); (3) a neurone system with cell bodies in the mesencephalon with medullated axones extending to the cord (mesencephalospinal neurone system); (4) a neurone system with cell bodies in the nuclei pontis and nuclei arcuati with medullated axones extending into the cord (pontospinal or metencephalospinal neurone system); (5) neurone systems from the formatio reticularis and nuclei laterales of the medulla oblongata to the lateral funiculi of the spinal cord (myelencephalospinal neurone systems); (6) a neurone system extending from the inferior olivary nucleus to the cord (olivospinal neurone system); (7) a neurone system the cell bodies of which are situated in the nucleus nervi vestibuli lateralis (Deiters'), the medullated axones going to the spinal cord (vestibulospinal neurone system); (8) various neurone systems with cells in the cerebellum and medullated axones going to the lateral and anterior funiculi of the cord (cerebellospinal neurone systems).

(1) *Thalamospinal Neurone System.*—Such a neurone system has for a long time been postulated. Meynert believed that many of the spinopetal funicular fibres arose in the thalamus, but the investigations which have been made since his time are conflicting. Meynert believed that the portion of the anterior funiculus of the cord, immediately adjacent to the anterior horn, came from the thalamus, but Redlich has destroyed the thalamus in animals and has studied human cases in which the thalamus was extensively diseased, but could obtain no evidence of the existence of thalamospinal fibres. It is still believed, however, by von Bechterew that fibres extend from the thalamus into the fasciculus lateralis proprius of the cord (*Seitenstrangreste*).

(2) *Rubrospinal Neurone System.*—Bouchard as early as 1866 drew attention to the fact that there was a distinct difference between the descending degenerations of the lateral funiculus in brain lesions and that in spinal-cord lesions, the latter being the more extensive. This indicated the presence of spinopetal fibres in the lateral funiculus other than the pyramidal tracts from the pallium. It was later shown, especially by experiments upon dogs, that the place of the pyramidal tracts could be taken in a functional way by these paths, especially by the one extending from the red nucleus and running in the lateral funiculus along with the pyramidal tract. This bundle of fibres, designated by von Monakow as the aberrant bundle of the lateral funiculus (*aberrierendes Seitenstrangbündel*), is usually referred to in the literature as von Monakow's bundle, sometimes as the "tractus tegmentospinalis." This neurone system has been studied by Held in the human fœtus, by Boyce in the cat, by Probst in dogs, by Russell and by Rothmann in monkeys. The medullated axones arise from cell bodies in the nucleus ruber, pass through the ventral decussation of Forel in the tegmentum, pass just medial from the lateral lemniscus and lower down between the superior olivary nucleus and the tractus spinalis nervi trigemini. In the medulla the fibres appear to be mixed up with those of Gowers' tract. In the lateral funiculus of the spinal cord these fibres assume in the cross-section the form of a comma, lying medial from the direct cerebellar tract, in the lateral and ventral part of the area corresponding to the lateral pyramidal tract. Some of the fibres extend into the lowermost part of the cord. It is this fibre system that appears to be able at times to replace the function of the pyramidal tract. It is the subcortical regulator of the movements of the extremities. It itself is under the influence of the cerebellifugal fibres of the brachium conjunctivum.

(3) *Mesencephalospinal Neurone Systems.*—Certain cell bodies in the middle and deep gray matter of the superior funiculus of the corpora quadrigemina (chiefly the nucleus centralis superior and the nucleus lateralis superior) give off medullated axones which run down in the funiculus anterior of the spinal cord. The medullated axones of this tract run through the dorsal decussation

of the tegmentum (*fontaineartige Haubenkreuzung* of Meynert), and having crossed the raphe lie in a separate bundle (in the cat), which runs just ventral from the fasciculus longitudinalis medialis, and is called by Tschermak the "predorsal longitudinal bundle." In human beings the fibres are probably mixed with those of the fasciculus longitudinalis medialis. Collaterals are given off to the eye muscle nuclei and to the gray matter of the formatio reticularis, but the main bundle runs down in the cord, where it occupies the anterior part of the fissural portion of the anterior funiculus. It becomes exhausted by giving off collaterals and terminals to the anterior horn of the same side, and partly by sending axones through the anterior white commissure to the contralateral anterior horn. Some of the fibres extend down as far as the lower part of the lumbar cord. It seems very probable that a part at least of Loewenthal's marginal fasciculus is identical with this system of fibres.

(4) *Pontospinal or Metencephalospinal Neurone System, and* (5) *Myelencephalospinal Neurone System.*—In the medulla and pons are situated groups of perikaryons which give off axones that run down to the spinal cord. Most of these are as yet very imperfectly understood. There is evidence, however, that some of the cells of the nuclei pontis and of the nuclei arcuati give off such axones. If so, we are justified in speaking of pontospinal neurone systems. A good deal of work has been done upon the descending fibre systems in the formatio reticularis—fibre systems which have their origin in perikaryons of the formatio reticularis grisea, specially in the inferior, middle, and superior central and lateral nuclei. Axones from the cells of the nucleus centralis medius run downward in the fasciculus longitudinalis medialis to reach the anterior funiculus of the cord, where they run close to the fissura mediana anterior. This is an uncrossed descending spinal neurone system from the formatio reticularis. Another fibre system from the central nucleus descends in the opposite lateral funiculus of the spinal cord occupying an area in the dorso-lateral region of the lateral pyramidal tract, medial from the rubrospinal fibre system and the direct cerebellar tract.

(6) *Olivospinal Neurone System.*—I have fully described this system on pages 954–958 of my book on "The Nervous System." The fibre system is usually known as Helweg's path, though it was described earlier by Paul Meyer. Its development has been studied by von Bechterew, who designates it the *Olivenstrang*. The path is seen as a triangular area in cross-section; hence Helweg's term (*Dreikantenbahn*). The cells of origin may be in the inferior olivary nucleus, or they may come from higher regions. Golgi studies are still lacking except for meagre statements in von Kölliker's text-book.

(7) *Vestibulospinal Neurone Systems.*—The cell bodies which give rise to the medullated axones of this path are situated chiefly in the nucleus nervi vestibuli lateralis (Deiters), though some of them may be situated in the nucleus nervi vestibuli superior of von Bechterew. The axones pass ventralward from Deiters' nucleus into the formatio reticularis alba and descend. On their way down they pass through the area situated between the nuclei laterales and the remains of the anterior horn. In the spinal cord they lie in the peripheral parts of the zone of exit of the anterior root fibres, and in the lateral portion of the funiculus anterior. Some of the fibres of this system descend as far as the lumbar cord. The axones appear to terminate by running in to end among the cells of the anterior horn of the same side. This neurone system is under the influence of impulses from the vestibular nerve on the one side and from the cerebellum (nucleus fastigii) on the other. Its influence on the cord is probably concerned with the coordination of the axis of the body and orientation in space.

(8) *Cerebellospinal Neurone System.*—Though a vast amount of work has been done with the idea of determining the fibre systems which throw the spinal cord directly under the domain of the cerebellum without the intermediation of any relay station, it must be confessed that our knowledge upon this subject is still, in reality, most meagre. Marchi early described a fibre system in the spinal cord which degenerated after removal of the cerebellar hemisphere. He thought that the fibres came chiefly from the vermis, partly from the hemisphere, that they passed through the brachium pontis, and then by way of the ground bundles into the anterior and lateral funiculi of the cord. He could follow the degeneration throughout the whole length of the cord. In cross-sections this degeneration occupied two areas, one extending along the periphery of the cord from the fissura mediana anterior to the anterior extremity of the direct cerebellar tract, that is, in an area corresponding to the *zone sulcomarginale* of Marie; the other, a more lateral area, situated just in front of the lateral pyramidal tract. It was his opinion that the fibres ran in to end in the anterior horn of the spinal cord. This degeneration, described by Marchi, probably corresponds, at least in part, to the so-called cerebellar tract of Loewenthal.

Ferrier and Turner dispute Marchi's conclusions, inasmuch as they found that when one hemisphere of the cerebellum is extirpated without injury to neighboring parts, no degeneration can be traced to the cord, though degenerated fibres can be followed through the corpus restiforme to the inferior olivary nuclei and the nuclei of the posterior funiculi. When the vermis is extirpated alone, the fibres which run to the nucleus nervi vestibuli lateralis of Deiters degenerate. It is their opinion that the degeneration, described by Marchi, occurs only when Deiters' nucleus is injured in the attempt at cerebellar extirpation. This view is supported also by the experimental work of Risien Russell and by that of Mott.

Marchi has, however, found a supporter in Biedl, who reproduced a degeneration of the fibre systems, described by Marchi, by cutting the corpus restiforme. He thinks, however, that Marchi's tract reaches the cord by way of the inferior cerebellar peduncle rather than by way of the middle cerebellar peduncle, as Marchi asserted.

The experimental work of Thomas tends to support Marchi's observation as far as the fibres in the anterior funiculus are concerned. He thinks that the fibres arise from cells in the nucleus dentatus, and that they pass through the superior vestibular nucleus of von Bechterew and the lateral vestibular nucleus of Deiters into the formatio reticularis, and thence into the anterior and lateral funiculus of the cord. His work was done chiefly upon dogs. Extirpation of the cortex of the cerebellum alone does not cause the degeneration; it is necessary to injure the nucleus dentatus cerebelli. If Deiters' and Bechterew's nuclei are also injured, the degeneration in the cord is much more extensive.

Ramón y Cajal has made an important contribution to the neurone system under discussion by the application of Golgi's method. He finds that the axones of the cells in the nucleus dentatus, passing out in the brachium conjunctivum, give off descending limbs of bifurcation which run to the anterolateral fasciculus of the cord. In his opinion it is these axones which correspond to the descending cerebellar path of Marchi. Ramón y Cajal emphasizes the fact that in frontal sections of the guinea-pig's brain, stained by the method of Weigert-Pal, this cerebellospinal path from the brachium conjunctivum can be clearly seen as isolated bundles. (See Fig. 439 on page 430 of his "Histologia del Sistema Nervioso de los Vertebrados.")

It may be regarded as certain, therefore, that a direct uncrossed cerebrospinal neurone system exists, the cell bodies of which are situated in the nucleus dentatus (and perhaps in the neighboring gray nuclei), the medullated axones of which go through the anterolateral white matter to the anterior horn of the cord. It would appear, too, that the fibre system, making up the spinal portion of this path, or a part of it, is really an offshoot or by-path from the main ascending fibre system of the brachium conjunctivum. The function of the path is doubtless coordinative. It seems probable that it carries to the anterior horn cells at least a part of those cerebellar impulses which maintain the equilibrium of the body.

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See also references under preceding heading.

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SPINAL-CORD DISEASES: ACUTE ASCENDING PARALYSIS.—(Synonym: Landry's Paralysis.) In 1859 Landry described the symptom complex which has since then been known both as Landry's paralysis and as acute ascending palsy. The clinical picture he portrayed was the following: The sudden development in a previously healthy individual of a flaccid paralysis of the legs, which generally began first in one and then within a few hours or a day affected the other. When the paralysis of the legs had become complete, the trunk muscles became paralyzed, and then in the space of a few days the arms were involved in like manner. Next there was involvement of the deglutition, articulation, and respiratory musculature, and in a short time death followed from asphyxiation. There are milder cases, however, in which there is restitution of function. Landry described prodromes, such as general malaise and paræsthesia in the extremities, and during the course of the illness slight disturbances of sensation. He laid particular stress on the absence of muscular atrophy, the presence of normal electrical reactions, and negative findings at the autopsies.

Since Landry's original cases were published, many cases, either similar to his or varying from the type in one essential or another, have been reported, until to-day our conception of the disease has broadened so as to include cases exhibiting a wider range of symptoms; so that, as Oppenheim says, the only essential symptom necessary to the disease is the rapid development of a flaccid paralysis, commencing in the lower extremities and affecting successively the arm and the bulbar nerves, though in rare cases the order of involvement is reversed.* In the literature under this heading have been included many cases which undoubtedly belong to other diseases, principally acute anterior poliomyelitis and multiple neuritis.

ETIOLOGY.—The disease is rather uncommon in its occurrence. Men are affected more often than women, and as a rule between the ages of twenty and forty, though instances of its occurrence in children and old people have been observed.

The view most generally held as to the etiological factor of the disease is that it is due either to some form of toxæmia or to bacterial infection. Landry himself was under the impression that it was caused by poisoning, and this opinion was accepted by many subsequent observers, but especially by Westphal. The following facts Diller regards as pointing in this direction: First, the presence in some cases of enlargement of the spleen and lymph glands, hemorrhagic spots in the lungs and intestines, and albuminuria; second, the finding of bacteria in some of the cases. The varieties found include anthrax, typhoid, and other unclassified bacilli, streptococcus, varieties of staphylococci, diplococci, and the Fränkel pneumococcus. No specific form of micro-organism has been isolated, but the disease seems to be capable of development after diphtheria, typhoid, variola, anthrax, pneumonia, pertussis, the puerperium, malaria, and probably also upon septicæmia as a basis. Oppenheim thinks it doubtful whether the entrance of the micro-organisms themselves into the spinal cord, medulla, and peripheral nerves can produce the disease, but he believes that probably their toxins injure the motor tracts in such a manner as to cause paralysis, without as a rule producing recognizable lesions. Thoinot and Masseline and Remmlinger have produced in rabbits symptoms similar to Landry's paralysis by the injection of micro-organisms into the circulation.

* In recent years some authors have regarded Landry's paralysis as being merely a symptom complex due to various causes and not a disease or clinical entity with a definite pathological basis.