SECONDARY DEGENERATION
following
UNILATERAL LESIONS
of the
CEREBRAL MOTOR CORTEX.

(An Experimental Research.)

Thesis submitted for the Degree of M.D. by

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PART I. INTRODUCTORY.

The following thesis contains a record of the results, anatomical and physiological, of a number of experiments undertaken at the suggestion of Professor Schäfer with a view to determine the path pursued by the fibres of the pyramidal tract in their course from the large pyramidal cells in the cerebral motor cortex to their termination in the lower levels of the brain and spinal cord, but more particularly their mode of ending in relation to the nuclei of the cranial nerves in the mid-brain, pons and medulla oblongata. Although this - the motor path - has been more carefully investigated and is probably better understood than any other tract or path in the central nervous system, still much remains to be discovered, especially regarding the terminal connections of its fibres with the motor nuclei of the cranial nerves and with the cells in the anterior horns of the spinal cord. Writing on this matter, Barker (93) says:- "The exact place where the fibres for these nuclei" (cranial motor nuclei) "leave the main bundles" (of the pyramidal tract) "and the exact path which they follow to the nuclei have not as yet been fully determined." . . . "The statement that nerve fibres from these bundles do pass to these nuclei is based mainly, but not solely, upon clinical experience, physiological experiment, and analogy." That is to say, the anatomical connections of the fibres of the pyramidal tract with the cells of the anterior cornua of the spinal cord and of the cranial motor nuclei have never yet been satisfactorily established, and it was with the object of throwing some light if possible on this subject that the work embodied in the present thesis was undertaken.

HISTORICAL ACCOUNT of PREVIOUS WORK.

Prior to the year 1861, that is to say, only about 40 years ago, it was believed by all anatomists and physiologists that the cortex of the cerebral hemispheres was not excitable by the application of a stimulus to it, and that there was no localisation of any particular function to any special part of the cerebrum, but that the cerebral hemispheres acted as a complete whole, and that any voluntary movement, or any change in the state of consciousness due to the incoming of any form of afferent impulse was effected by all parts of the cerebrum acting together. This doctrine was supposed to be established beyond dispute by the experiments of Flourens[1] which consisted in removing the hemispheres wholly or partially from animals and noting the effects produced. In summing up his results, he says :- "Enfin, dès qu'une perception est perdue, toutes le sont; dès qu'une faculté disparait, toutes disparaissent. Il n'y a dont point de sièges divers ni pour les diverses facultés, ni pour les diverses perceptions. La faculté de percevoir, de juger, de vouloir une chose reside dans le meme lieu que celle d'en percevoir, d'en juger, d'en vouloir une autre; et consequemment cette faculté, essentiellement une, reside essentiellement dans un seule organe." This doctrine, as opposed to that of the school of Gall[2], was warmly supported by Majendie and all the other eminent physiologists of the day, and even as late as 1876 Brown-Séquard[3] still held the same opinion.

In 1861 an important discovery in the localisation of function in the cerebral hemispheres was made by the French physician Broca[4], as the result of clinical and pathological observation. He observed that when the posterior part of the inferior left frontal convolution was destroyed by rupture of a bloodvessel, or otherwise, in a right-handed person, there was generally loss of the power of speech, or rather loss of the power of remembering words required for speech. This is the first distinct evidence we have of cerebral localisation. Shortly thereafter the Flourens doctrine was again challenged by Hughlings Jackson[5] of London. He observed that in certain cases of epilepsy he could trace the cause to some injury of the skull or cerebral cortex. In such cases the convulsive movements began in some particular part and spread from that part, e.g. began in the fingers and spread up the arm, the movements following a certain order or "march." From these clinical and pathological observations Jackson reasoned that the irritation produced by the injury or disease of the cerebral cortex in the region now known as the Rolandic area was the cause of the convulsive movements or "fit." This is the first idea we get of "motor localisation." With Jackson at that time it was only a hypothesis, but since then this has been abundantly proved to be correct. In 1870 Fritsch and Hitzig[6] showed that stimulation, by galvanic electricity, of certain parts of the cerebral convolutions surrounding the crucial sulcus in the brain of the dog led to certain definite movements of the limbs on the opposite side of the body, stimulation of the same part of the cortex always producing the same movement of the limb. They also found that extirpation of these particular parts of the cortex led to paralysis of the same muscles as were excited by stimulation. Stimulation of other parts of the cortex could not be made to produce these movements. This is the first direct proof of a cerebral cortical motor area. In 1873 Ferrier[7], using faradic electricity as a stimulus, repeated the experiments of Fritsch and Hitzig on cats, dogs and monkeys. He confirmed their observations and greatly extended them. He was able to localise and map out, especially in the monkey, those areas which on stimulation produced movements of the face, arm, trunk, and leg of the opposite side of the body. He added many new facts regarding motor centres, and he was the first to discover sensory centres. These general results of Ferrier's experiments were subsequently much amplified by Horsley and Schäfer[8], and later by Beevor and Horsley[9], and now as regards the brain of the monkey our knowledge of these cortical motor areas is as accurate as the nature of the methods of investigation will permit.

The cortex of the Orang-utang has been explored by Beevor and Horsley[10], and they found that, while the excitable areas in the main corresponded to those in the macaque monkey, yet there was one marked difference, viz., that the excitable area was not continuous as in the monkey but was interrupted by small areas, stimulation of which produced no movement of any muscle. In a few cases also, chiefly in America, [11,12,13,14,15] the human brain has been proved to be directly excitable by electrical stimulation. In these cases the areas under observation were necessarily limited, but in the main they are found to correspond to those mapped out on the brain of the monkey.

We must next consider the path pursued by the fibres which carry the impulses from the cells situated in the motor cortex to the cells of origin of the motor cranial nerves and of the anterior spinal nerve roots, that is to say, the fibres which together make up the pyramidal tract. Several methods have been employed for investigating the course of these fibres.

1. EMBRYOLOGICAL METHOD of FLECHSIG. First may be mentioned the embryological method or method

of Flechsig[16] which depends upon the fact that the nerve fibres of different tracts in the central nervous system put on their myelin-sheaths at different dates in the process of development, e.g. the axones of the sensory neurones (by the term neurone is here meant the cell body or perikaryon and all its processes)in the spinal cord and medulla oblongata put on their myelin-sheaths before those of the motor neurones. At or shortly before birth, in the human subject and in all animals which are unable to walk when born, all the fibres of the spinal cord have become myelinated, except those of the pyramidal tract. If sections be made of the embryonic cord or brain at the proper age and stained by the Weigert-Pal method, the regions occupied by the fibres which are not myelinated stand out in the sections as clear areas, those fibres which are possessed of myelin-sheaths being stained black, and those which have not yet developed myelin-sheaths remaining unstained. By this method Flechsig has been able to make out the pyramidal and many other tracts in the central nervous system.

2. METHOD of ELECTRICAL STIMULATION. This method

which has yielded such valuable results in the localisation of the cortical motor areas, has also been employed successfully as a means of localising the functions of the fibres in the corona radiata, internal capsule, &c. It was first so applied to the corona radiata by Burdon-Sanderson[17] in 1873 and by Franck and Pitres[18] in 1887 and since then by many other experimenters. In this case the electrodes are applied directly to the fibres in transverse section at the different levels. Beevor and Horsley[19] determined the arrangement of the motor fibres in the internal capsule in the bonnet-monkey and in the orang-utang by this method, while Gad and Flatau[20] have recently (1897) applied it in an attempt to localise the relative positions of the leg and arm fibres in a transverse section of the crossed pyramidal tract in the spinal cord of the dog. In 1895 and again quite recently in 1900 Hoche[21] was permitted to faradise the caudal end of the divided spinal cord in the mid cervical region in the case of several decapitated criminals. He was able to stimulate the divided cord within two minutes after it had been cut across by the guillotine. He then obtained movements of all the limbs - - often bilateral from stimulating one-half of the cross section - but he was not able to obtain any localisation of fibres in the crossed pyramidal tracts such as was described by Gad and Flatau in the dog.

3. THE METHOD of GOLGI has been used chiefly for investigating the origin and termination of the pyramidal fibres, and their relation to the cell-bodies of other neurones, and in the hands of Ramon y Cajal (22) and others it has rendered valuable results, when applied to the study of the minute structure of the cortex, but it is not a method suitable for tracing the course of fibres of more than microscopic length, and nothing more need be said about it in this relation.

4. The WALLERIAN or DEGENERATION METHOD. This is the method which was first in the field, and which has probably been more fruitful than any other in advancing our knowledge of this subject. It depends upon the fact, first discovered by Waller(23) of London about the year 1850, that when a nerve fibre is cut off from that part of its cell of origin containing the nucleus, it undergoes degeneration. Any lesion in the brain or spinal cord which so cuts off a fibre or tract of fibres

leads to a degeneration of that fibre or tract of fibres - descending if the cell be above the lesion, ascending if the cell be below it. Such a lesion may be produced experimentally on one of the lower animals anaesthetised, or it may occur in the human subject as the result of accident or disease. By certain methods of staining, which will be given in detail subsequently, it is easy to distinguish degenerated parts in sections of the brain or spinal cord if the lesion is followed by death within certain limits of time. As this is the method which has been employed in the present investigation, I shall give a short review of the facts which ~~this method~~ it has brought to our knowledge regarding the course of the fibres of the pyramidal tract.

As a matter of fact the earliest observer to study the minute anatomy of the brain by the method of degeneration was Cruveilhier[24] in 1835, but he did not understand the principle on which the changes that he observed depended. It was Türck[25] in 1851 who gave us the first complete account of the descending tracts. In certain long-standing cases of hemiplegia he observed in transverse sections of the pons, bulb and spinal cord certain areas which, as he termed it, had become "secondarily diseased".

He was able in this way to locate the motor path in the internal capsule, crusta, pyramidal bundles of pons, anterior pyramids of medulla oblongata, and the crossed and direct tracts in the spinal cord. He also made out the pyramidal decussation in the bulb and was the first to observe a direct or uncrossed tract in the spinal cord. This tract was subsequently named by Charcot "the column of Türck."

The next in the field was Bouchard[26] in 1866. In a series of articles published in the Archiv. General de Medicine of that year he gives the results of his observations of secondary degenerations following lesions in the cerebral hemispheres, cerebral peduncles, pons, bulb, spinal cord, and posterior nerve roots in the human subject, produced by tumour, haemorrhage or compression. He was able to make out in the main the descending tracts (motor) as we know them now. He found that following lesions of the encephalon the descending degeneration was not scattered over the whole extent of the antero-lateral columns of the cord. He found that most of the fibres which the brain sends to the spinal cord cross the middle line at the lower part of the bulb to take up a position in the posterior part of the lateral column of the opposite side in the cord, a position which they retain throughout the whole length of their course. They gradually ended in the grey matter of the cord and became fewer and fewer from above downwards, but some could be traced to "l'extremité inferieure de l'axe rachidien." This tract he called the "faisceau encephalique croisé ou externe." He further found that the crossing of the pyramids was not complete. Some fibres passed down along the side of the anterior median fissure, gradually became lost in the grey matter of the cord, and could not be traced below the middle of the dorsal region. "Cet ensemble de fibres que l'encephale envoie a la moelle sans entrecroisement, et qui se loge a la partie interne du cordon anterieur, vous l'appelerons faisceau encephalique direct ou interne." The degeneration did not extend into the roots of the spinal nerves and from this he concludes that the degenerated fibres end in the grey matter of the spinal cord. He recognises, as Türck and Gubler[27] had done before him, the great importance of this method which Waller had applied to the study of the peripheral nerves, as a means of investigating the minute anatomy of the brain and spinal cord.

Following this important communication valuable work on the same lines was done by Charcot,[28] Pierret,[29] (who investigated the ascending degeneration resulting from lesions of the posterior nerve roots), and Nothnagel.[30] They confirmed in the main the observations of Bouchard.

We now come to a new departure in the mode of investigation which consists in simulating artificially in animals the lesions produced by disease or accident in man. In 1877 and 1878 Franck and Pitres[31] removed the cortical centre for the left fore limb in one dog, and the whole of the right sigmoid gyrus in another. The one died nine months and the other was killed six months after the operation. Motor paralysis of the opposite side resulted, and along with this there was some sensory disturbance, but both were quickly recovered from, and in neither case was there any contracture of the paralysed limbs as had so often been observed in cases of hemiplegia in man. In both cases they found degeneration in the lateral columns of the spinal cord of the opposite side. But from their paper it may be gathered that the secondary degeneration in these two cases might have been, in their opinion, accidental, and that it was not always a necessary result of cortical ablation.

In 1882 Moeli and Binswanger,(32) and later Moeli(33) working alone found that after injury to or removal of the motor cerebral cortex in the dog secondary descending degeneration always followed. The animals had been operated on by Munk, and they showed partial motor and complete sensory paralysis of the opposite side. Binswanger,(34) who had done similar experiments previously, had denied that this was the case, but he now corrected this statement and gave as the reason of his failure that he had allowed the animals to live too long after the lesion had been produced. Moeli and Binswanger often found secondary degeneration in the brain and spinal cord in animals in which there had been no evidence of motor paralysis during life.

In 1883 Schäfer(35) was given, for microscopical examination, the brain and part of the spinal cord of a monkey, which some months previously had had "the whole of the centre of the fronto-parietal region on the left side of the cerebrum" removed by Ferrier and Yeo. There was no injury to the corpus striatum or optic thalamus ; it was a purely cortical lesion. He found degeneration in the internal capsule

~~Opposite~~ To face bottom of p. 14.

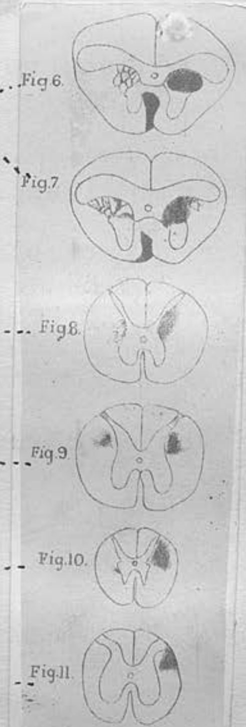
At the decussation of the Pyramids

Immediately below the decussation

At the cervical enlargement of sp. cord

Through middle of dorsal region

From the lumbar region



Photograph from Plate accompanying Schäfer's Paper.

middle portion of crusta, pons and medulla oblongata - all on the side of the lesion. In the lower part of the bulb in the region of the pyramidal decussation he found that "the degenerated tract passes obliquely across the anterior median fissure to the opposite or right side of the medulla. Here it runs down for a short distance in the formatio reticularis. A portion of the tract remains, however, at first in the anterior column and this portion, or at least a considerable part of it, at a little lower level appears to be passing towards the formatio reticularis of the same or left side of the medulla". In the cervical part of the cord the crossed pyramidal tract of the right (opposite) side was degenerated as was to be expected "but what was not to have been expected is the presence of another patch of degeneration upon the left side of the cord (side of injury) occupying almost exactly the same position and of the same extent as the degeneration on the right side, but less accentuated by the process of staining employed and therefore probably containing fewer degenerated fibres. The degeneration in the cervical cord is therefore bilateral." The sections from the dorsal and lumbar regions of the cord were prepared and examined by Ferrier, and in these there was no evidence of any degeneration on the same side as the lesion - it was limited entirely to the crossed pyramidal tract of the opposite side. This is the first recorded observation of a bilateral lateral column degeneration in the spinal cord following a unilateral cortical lesion in the cerebrum, and the explanation offered at that time by Schäfer as the probable one has since been proved to be correct. He says:- "The only gleam of elucidation as to the source of the degenerated fibres in the left lateral column in this (cervical) region which it has been possible to obtain is to be found in the observation above recorded of the apparent passage of a small part of the degenerated left anterior pyramid towards the left lateral column, whilst the larger part took the more usual course towards the opposite lateral column. I have searched in vain for any sign of degeneration along the pyramidal tract of the right side of the medulla, pons and crus cerebri, and of the right internal capsule."

Shortly after this, in 1884, Pitres[36] published the results of his examination of forty cases of long-standing hemiplegia, and in ten out of these forty cases he got descending degeneration in the lateral columns of both sides of the cord. Türck, Flechsig and others had described bilateral degeneration of the cord after bilateral cerebral lesions, "but", he says, "no author so far as I know, has as yet described symmetrical degeneration of the lateral columns of the spinal cord, following unilateral cerebral lesions." This was true only of the human subject, for Schäfer had described it in the monkey in 1883.

The explanation of this bilateral degeneration of the lateral (crossed) pyramidal tract in the cord as the result of damage to one side of the cerebrum was for a long time a source of fruitful discussion. Clinical evidence of a bilateral motor distribution from one side of the brain was known long before the observations of Schäfer and Pitres. Brown-Sequard (37) long ago pointed out that in cases of hemiplegia the so-called sound side is never so strong as it was before the attack, - that there is always a certain amount of weakness in the non-paralysed side, as well as marked weakness or complete want of power in the paralysed side. In 1875 Westphal (38) remarked that in certain cases of hemiplegia with contracture, the so-called sound lower limb showed ankle clonus. In 1878 Dejerine (39) observed the same phenomenon - ankle clonus in the so-called sound lower limb, and to explain it he put forward the hypothesis that it was due to a descending sclerosis of the pyramidal bundle of the sound side. In 1880 Brissaud (40) described contracture in both lower limbs which he had sometimes found in hemiplegias. In 1880, and again in 1882, Pitres (41) studied these bilateral symptoms clinically, and often found evidence of some paralysis on the sound side in cases where the post mortem examination showed the lesion to be strictly confined to one side of the cerebrum. In some cases he stated that the so-called sound upper limb loses as much as 38·5 per cent of its original power and the lower limb 50 per cent. In 1883 Dignat, (42) and in the same year Friedländer, (43) made more accurate observations with the dynamometer, and both found that there was always a considerable loss of power on the non-paralysed side.

Charcot (44) attempted to explain the partial paralysis of the "sound side" on an anatomical hypothesis, which would also account for the descending bilateral degeneration in the spinal cord. He held as possible that some of the fibres from the crossed pyramidal tract "pass through the anterior commissure, especially in the dorsal region and gain the lateral column of the opposite side to descend with it into the lumbar region. There exists then for these fibres a double decussation - one in the bulb (anterior pyramidal decussation), and the other at different points throughout the whole dorsal region of the cord."

Following Schäfer in the monkey and Pitres in man, Langley and Sherrington (45) in 1884 found in a dog from which Goltz had removed a large area of the cerebral cortex and which was exhibited by him at the International Medical Congress held in London in 1881, sclerosis in the lateral pyramidal tract on each side of the cord which they were able to trace as far as the lumbar region. They found only unilateral degeneration above the pyramidal decussation.

Again in 1885 Loewenthal (46) found in the dog bilateral cord degeneration after unilateral cortical lesions.

In the same year Sherrington (47) began an elaborate research into the nature and origin of this bilateral degeneration in the spinal cord which was now considered to be an established fact. His first observations were made on material obtained from dogs which had been operated on by Goltz. He found "1. That injury to the 'cord-area' of the cortex of one hemisphere causes degeneration in both halves of the spinal cord in the dorsal angle of the lateral column, and that there is no reason to think this bilateral degeneration is a degeneration of the two crossed pyramidal tracts; 2. that the clinical symptoms of a unilateral cortex injury become bilateral and accord with the bilateral anatomical change." The degeneration in the cord on the same side as the cortical lesion was not so far advanced as that on the opposite side, and this he supposed to be due to the fact that the degeneration on the same side was of more recent date. This tract on the same side he called the "re-crossed" tract, supposing that its constituent fibres crossed over in the cord from the opposite degenerated pyramidal tract. These fibres, he believed, crossed the middle line twice - once in the pyramidal decussation and a second time back again to the same side in the cord. He did not think that this recrossed pyramidal tract represented in any way the direct pyramidal tract in man. Both crossed and re-crossed tracts he was able to trace as far as the 2nd lumbar nerve root.

Regarding this re-crossing of the fibres in the cord Sherrington was supported by Homen and others. Homen[48] in the same year after hemisecting the cord in dogs in the cervical region found some degenerated fibres in the crossed pyramidal tract of the opposite side, and these fibres he concluded must cross in the cord. He also stated that he found degeneration of the direct pyramidal tract in the dog, but in this he was certainly in error, what he saw being evidently a portion of the descending antero-lateral tract of Loewenthal.

Others again denied the existence of the "re-crossed" tract of Sherrington, and denied even the existence of a bilateral degeneration in the cord. For example, Ziehen[49] in 1887 extirpated the motor areas on one side in three dogs, and found in the spinal cord the degeneration limited to the crossed pyramidal tract of the opposite side - no degeneration on the same side. Mott[50] likewise in 1891, after hemisection of the cord in monkeys, denied any evidence in favour of a re-crossing of pyramidal fibres in the cord.

In 1889 Tooth,[51] examining material obtained from monkeys in which Horsley had removed partially or wholly the motor cortex on one side, found in the cord very obvious degeneration of the crossed pyramidal tract of the opposite side, but only a very slight degeneration of that of the same side.

In a case of right-sided hemiplegia, due to haemorrhage in the left internal capsule in the human subject, Hadden and Sherrington (52) in 1886 found the left pyramid degenerated and the right very slightly. They observed a great diminution in the number of degenerated fibres in the region of the pyramidal decussation as the tract passes from one side of the bulb to the opposite side of the cord, and they found a doubly bilateral degeneration in the spinal cord - a degeneration of both crossed and both direct pyramidal tracts. It seemed difficult to explain this as the result of a unilateral lesion unless the view of Hamilton were correct, viz., that fibres from the cortex of one hemisphere cross in the corpus callosum and descend through the opposite internal capsule. In a paper published in 1884 Hamilton (53,54,55) made the statement that "the corpus callosum is not an interhemispheric commissure at all but is the decussation of the cortical fibres in their progress downwards to become connected with the basal ganglia. In the human brain I have never seen any fibres which pass directly from one hemisphere to another." This view was strongly opposed by Beevor (56) and others, at that time, and since then it has been abundantly proved to be quite erroneous.

In 1889 France (57) published a paper giving the results of an investigation into the degenerations following removal of the gyrus fornicatus and gyrus marginalis in six monkeys (used in localisation experiments of Horsley and Schäfer) and also following removal of the external motor cortex (3 cases) and of the whole motor cortex (external and mesial) (4 cases). After removal of the external motor cortex he found degeneration in the middle third of the internal capsule. It did not, however, involve the whole breadth of the capsule but left the inner border almost entirely free. This inner border was occupied by fibres from the marginal convolution "as is proved by the fact that when the entire motor area (including the gyrus marginalis) is removed the whole width of the internal capsule is degenerated." In the crusta the degeneration occupied the middle third both after removal of the whole and of the external motor cortex alone, but in the latter case the degeneration was greater along the ventral than along the dorsal border of the crusta. "In the medulla the whole area of the pyramid is degenerated in those cases where the whole motor area was removed, whilst in those where only the external motor area was involved a part along the posterior mesial border appears less degenerated than the rest." Throughout the spinal cord the crossed pyramidal tract of the opposite side was degenerated down to the level of the 3rd or 4th lumbar nerve. The fibres from the marginal convolution were found to border on the direct cerebellar tract. According to his results the fibres from the marginal convolution occupy more or less the inner border of the internal capsule (next the optic thalamus), the anterior portion of the crusta, the postero-mesial border of the pyramid, and in the cervical cord that portion of the crossed pyramidal tract lying next the direct cerebellar tract. In the dorsal and lumbar regions of the cord the position of the degenerated fibres from the marginal convolution within the area of the crossed pyramidal tract could not be localised. No mention is made of any degeneration in the crossed pyramidal tract of the same side. In no case was any degeneration observed in the anterior columns.

In 1889 Sherrington[58] gave the results of experiments which he had performed on dogs and monkeys with the object of finding out "to what extent in the pyramidal tract there is a grouping of nerve fibres corresponding to the grouping of nerve cells in the 'cord area' of the cerebral cortex." By 'cord-area' of cortex he meant that area, injuries to which are followed by degeneration of nerve fibres in the spinal cord. He found no grouping of the arm or leg fibres in the cord. After very small cortical lesions within the arm and leg centres degenerated fibres were found scattered over the whole transverse area of the tract in the spinal cord, medulla, pons and crusta of mid-brain. In every case a unilateral cortical lesion or hemisection of the spinal cord was followed by degeneration in the pyramidal tract below in both lateral columns of the cord. Counting the degenerated fibres the amount of degeneration on the same side varied in different cases from $^1/100$th to $^1/5$th of that on the opposite area. In one dog he saw slight degeneration of the opposite pyramid above the decussation. From the degenerations the following points were made out for the "re-crossed tracts" :-

"1. They consist of fibres derived from the crossed tract of the opposite half of the cord and are directly connected (i.e. without the intermediation of nerve cells) with that cortex which is the place of origin of the crossed tract whence they came."

"2. Their path of connection with the cortex twice crossed the median line, the proximal crossing being at the pyramidal decussation."

x x x x

"4. They occupy the same area in a transverse section of the cord as does the crossed pyramidal

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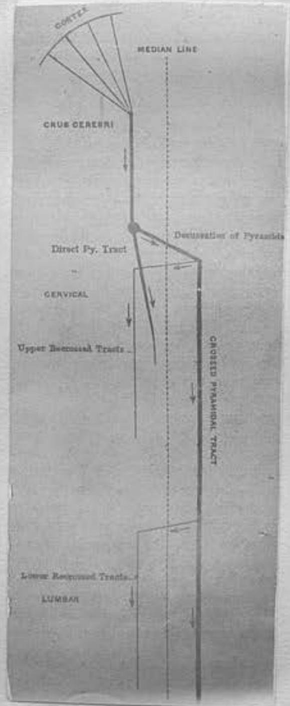

Photograph of diagram accompanying Sherrington's article.

tract, amongst the fibres of the crossed tract from the left hemisphere being scattered those of the 're-crossed' tract from the right hemisphere."

x x x x

"Insistence may be laid upon the pyramidal tract as a line of <u>direct</u> communication of each hemisphere of the brain with <u>both</u> halves of the spinal cord, not with one only as generally described."

He also found that the fibres of both the crossed and "re-crossed" tracts diminish most rapidly in number in the lower parts of the cervical and lumbar enlargements after lesions of the arm and leg areas respectively, and in face area lesions the diminution takes place most rapidly in the pyramid just below the pons, and he infers from this that the fibres which are lost end in grey matter in these regions.

Shortly after this in an addendum to the last communication, Sherrington (59) withdraws the term "re-crossed" fibres. He had now found bilateral degeneration in the pyramidal tracts at the base of the brain in monkeys as he had once before in the dog and once in man (already mentioned), but he does not state exactly where he supposes the degenerated fibres are derived from or at what point they cross the middle line. He says: "The diagram" (see photo opposite page) "I would therefore amplify by a branch from the pyramidal tract crossing the median line at the base of the brain and descending parallel to the median line in the pyramid of the side opposite to the cerebral lesion" . . . . "As the name 're-crossed' cannot be given to the branch tract from the main pyramidal crossing the median line at the base of the brain, that name seems on the whole unsuitable for use." He does not say whether he supports Hamilton in supposing that the fibres cross in the corpus callosum.

Still continuing his researches on this subject in a paper published in 1890, Sherrington (60) states that when following a cortical lesion, the pyramidal tract degenerates, scattered fibres are found undergoing degeneration in the anterior grey horn of the spinal cord, lateral grey horn, "isolated grey masses in the pons lying close to fibre bundles of the crustal tracts among the deep transverse pontial fibres" (he means, I suppose, the nuclei pontis) . . . . and in the substantia nigra in the midbrain. These fibres in the grey matter were always of smaller size than those of the pyramidal tracts and this he supposes to be due to the subdivision of the pyramidal fibres before entering the grey matter. In cortical lesions confined to the leg area be still found many degenerated fibres in the substantia nigra of the crus.

In 1890 Langley and Grünbaum (61) investigated the degeneration following the removal of a cerebral hemisphere in a dog operated on by Goltz and exhibited by him at the Physiological Congress at Basle in 1889. They describe complete degeneration of the pyramid, atrophy of the substantia nigra, tegmentum, and grey matter of aqueduct on the same side as the lesion. There was the usual unilateral degeneration in the crusta, pons and medulla oblongata, and bilateral degeneration in the cord, but in the crossed pyramidal tract of the same side the degeneration was very slight.

The study of degeneration had up till this time been carried out by staining the sections with carmine, aniline blue-black, or by Weigert's method or Pal's modification of that method, but since 1891 the much more accurate and delicate method of Marchi (62) has been employed by almost all investigators, and the introduction of this method in 1887 marks an epoch in the history of the study of degeneration in the central nervous system as had that of Golgi in relation to the structure of the grey matter. By this method it has been possible to trace the distribution of the pyramidal fibres and even of the collaterals given off by these fibres with far more exactness than was possible with the older methods, and consequently the results are much more valuable. Of course in only a limited number of cases in the human subject is it possible to employ the Marchi method - only in cases which terminate fatally not earlier than about 7 days and not later than about 2 months after the occurrence. of the lesion which has led to the degeneration. If the degeneration be of longer duration than about two months then the Weigert-Pal method must be had recourse to. For some time after its introduction it was decried by many eminent neurologists as a method which was quite unreliable, but the errors which were made by Marchi in his earliest applications of the method were largely responsible for this. Amongst the first investigators in Germany to recognise its value were Singer and Münzer [63]. They used it as a means of tracing degeneration in the optic nerve and tract, but subsequently they employed it in investigating motor degeneration.

One of the earliest touse this method in tracing motor degeneration was Sandmeyer [64] in 1891. He removed the arm, leg and face cortical centres in dogs on one side. Thirteen animals were used, and in seven of these the degenerations were investigated by the Marchi method. He found the usual unilateral degeneration in the medulla oblongata and pons, and he sometimes found a bilateral degeneration in the lateral columns of the spinal cord but not always. In no case did he find a direct pyramidal tract in the dog. He makes no mention of having traced any of the degenerated pyramidal fibres to their termination in the grey matter either in the cord or brain.

Max Herz,(65) at a meeting of the "Gesselschaft der Aerzte in Wien" on 27th February 1892, exhibited microscopical preparations of sections of spinal cord of a monkey which died 5 months after the right motor cortex was removed. These showed degeneration in both pyramidal tracts, but much less in the uncrossed than in the crossed tract. He employed the Weigert-Pal method of staining as he was precluded from using the Marchi method by the age of the degeneration.

In 1893 Muratoff(66) used dogs which were killed from 2 to 4 weeks after production of experimental lesions, and the material was prepared by Marchi's method. After stimulating to localise he extirpated the arm, leg, face, or whole motor area as the case might be. He found the usual unilateral degeneration on the side of the lesion in the crusta, pons, and medulla oblongata. From the crusta he describes degenerated fibres passing backwards into the tegmentum which he figures as going towards the central grey matter in the region of the nucleus of the 3rd nerve. In the cases in which the face centre alone was extirpated, he describes at the level of the 7th nucleus degenerated fibres passing off from the inner and posterior angle of the pyramid and after crossing the raphe going in the direction of the nucleus of the 7th nerve. In cases in which the arm and leg areas respectively had been removed alone no such fibres were to be seen. He observed degenerated fibres in both lateral columns of the spinal cord, and he describes the passage of some degenerated fibres at the decussation into the crossed pyramidal tract of the same side as the lesion. Risien Russel (67) claims to have been the first to observe the bifurcation of the pyramidal tract, at the decussation in a cat in which there had been an arrest of development of the pyramidal tract on one side, but Muratoff's observations were placed on record prior to the publication of Russel's paper. In this animal about 1/5th of the fibres were uncrossed at the decussation and could be seen passing backwards and outwards to take up a position in the crossed pyramidal tract of the same side in the cord.

In 1894 Sherrington, (68) again taking up this subject, removed a small piece of the cortex from the left arm area of four monkeys and killed them from 14 to 28 days after the operation. He confirmed the observation of Muratoff as to the bifurcation of the pyramidal tract at the decussation. In one of the experiments he found as many as 1/4th of the degenerated fibres uncrossed inthe lateral column of the same side of the cord. He also found that the degenerated fibres did not extend below the lower end of the cervical enlargement.

Mellus (69,70) in 1894, under the direction of Horsley, produced experimental cortical lesions in fourteen bonnet monkeys. He removed small areas from the left motor cortex; in 3 cases he removed the hallux-centre, in 4 cases the thumb-centre, and in 7 cases different centres within the facial area. The animals were killed in from 10 to 35 days and the brain and cord in each case prepared by the process of Marchi. He attempted to trace the commissural, association and projection fibres which had degenerated as a result of the lesions.

We shall confine our attention exclusively to the projection fibres. In every case coarse and fine fibres were found. In the case of the hallux-centre the degenerated fibres passed through the mesial part of the centrum ovale to the middle third of the internal capsule, and from there most of the fine fibres passed into the optic thalamus. In the crus the degenerated fibres were comparatively evenly scattered over the middle third. At this level many of the coarser fibres entered the substantia nigra. At the pyramidal decussation the degenerated fibres divided into three parts - most crossed to descend in the lateral column of the opposite side of the cord (crossed pyramidal tract), a smaller number passed into the lateral column of the cord on the same side - (from $^1/3$ to $^1/20$ of the whole in the different cases) - and a few passed down the anterior column of the cord of the same side (direct pyramidal tract). There was no apparent localisation of the degenerated fibres to any particular part of the tract - they were scattered over the whole area of the cross section on both sides. Degenerated fibres in all three tracts were found at the level of the 3rd sacral nerve root.

From the thumb-centre. Most of the fine fibres ended in the optic thalamus. In one or two cases he found fine fibres in the right internal capsule on the side opposite to the lesion. These ended in the right thalamus and came from the thumb centre on the right side and not from the corpus callosum. In the crusta again the degeneration was scattered evenly over the middle third, the fine fibres took up a position external to the coarse and a great number of both passed into the substantia nigra. On the right side in one or two cases degenerated fibres reached the crus from the right internal capsule and ended at that level in the substantia nigra. Many of the fibres on left side were lost inthe pons and medulla oblongata, but their ultimate distribution could not be traced. In three cases the decussation at the lower end of the bulb was complete, and in only one (out of four) was there fibres traced to the uncrossed lateral and direct anterior pyramidal tracts of the same side. The fibres began to disappear at the level of the 7th cervical root, and they had all disappeared at the level of the 3rd dorsal root.

From the Facial Area degenerated fibres were again traced into the internal capsule gradually passing from before backwards in the different levels of the capsule. Most of the fine degeneration again passed into the optic thalamus, but this was not so in every case. In several of the cases there was degeneration in the internal capsule of the right side traceable again to the corresponding areas in the motor cortex of the same (right) side. From the crusta many of the fibres passed to the substantia nigra, "and the remaining degenerate fibres begin to leave the left pyramid at the junction of the pons and medulla passing as single degenerate fibres to the facial nucleus of one or the other side. Below the level of the facial nuclei these fibres pass to the motor nuclei of the glossopharyngeus and vagus on both sides, the majority crossing the raphe to reach the nucleus of the opposite side. Occasional fibres were observed which apparently passed to some termination dorsal to these nuclei. This movement of degenerated fibres continued as far as the sensory decussation."

Mellus is the first observer by the degeneration method who has described degenerated fibres passing to the cranial motor nuclei.

In the same year (1894) Boyce[(71)] in the course of a very extensive research removed in the case of four cats the whole motor area on one side and traced by the Marchi method the resulting degenerations. He found degenerated fibres from the internal capsule passing into the optic thalamus, and some ending in the lateral geniculate body. There was uniform degeneration in the crusta - not limited to any particular part of it. He found no degenerated fibres in the opposite internal capsule, and on this point he does not confirm the results of Mellus in the monkey. The degenerated pyramidal tract divides into two parts at the decussation - most crossing to lateral column of opposite side of cord, and very few passing to the same side. No direct pyramidal tract was observed in the cat. The degenerated fibres were scattered evenly throughout the whole areas occupied by them. He agrees with Muratoff and Mellus that a few fibres leave the pyramid in the medulla at its inner and posterior angle but he has never been able to trace these or any other fibres coming from the degenerated pyramid to any of the cranial nerve ~~roots~~ nuclei.

In 1896 Dejerine and Thomas[72] published results of seven cases in the human subject of total degeneration of the pyramid following unilateral hemispherical lesion. They showed in all these cases a degeneration of the direct pyramidal tract in the anterior column of the cord on the same side as the cerebral or pontal lesion; a degeneration of the crossed pyramidal tract of the side opposite to the lesion, and a slight degeneration in the crossed pyramidal tract on the same side as the lesion. In two of the cases, one of which was a recent case and suitable for Marchi staining, they were able to trace the passage of degenerated fibres at the decussation to both lateral columns of the cord, while some remained in the anterior column of the same side. The fibres which pass to the lateral column of the same side these authors termed "homolateral pyramidal fibres", while those going to the opposite side they called "heterolateral fibres." They traced the crossed pyramidal tract to the level of the upper end of the filum terminale, the direct and homolateral tracts they traced to the level of the 4th sacral root - further than any of these tracts had ever been traced before. They found no degeneration in the anterior pyramid of the opposite side above the decussation.

In 1896 Rothmann (73), working in Munk's laboratory, examined the brains and cords of eleven dogs and two monkeys in which the fore and hind limb areas had been extirpated by Munk on one side. In some cases he used the Marchi method, and in others the method of Weigert. In every case he observed a bilateral crossed pyramidal tract degeneration in the cord up to four weeks after the lesion. It was much less abundant on the same than on the opposite side. In the course of from two to four months the degeneration on the same side had disappeared. The degeneration on the same side begins at the decussation and he comes to the conclusion that it is due to pressure at the crossing of the swollen bundles of the degenerating pyramid on some of the fibres of the normal pyramid. A view somewhat similar to this had been held by Hallopeau(74) as early as 1871. Rothmann says that a crossing within the cord does not exist.

Taking up this matter quite recently Rothmann(75) has come to a different conclusion. Munk removed the leg and arm centres on the left side in a monkey, allowed the animal to live 4 months and 13 days before killing it, he did a similar operation on the right side. Rothmann prepared the cord and medulla oblongata by the Marchi method, and he was able readily to distinguish the old from the new degeneration by the fact that in the case of the old the course of the fibres was marked by fine black points, whereas in the new the degenerated stained myelin was disposed more or less in the form of continuous black lines. In the upper and lower parts of the decussation, the crossing of the fibres is complete, but in the middle portion of the decussation some fibres from the right pyramid (recent degeneration) were observed going to the right crossed pyramidal tract. These could not be due to pressure from the bundles of the left pyramid as that pyramid had undergone degeneration long before. Rothmann doubts no longer the existence of fibres passing from each pyramid in the medulla to the crossed pyramidal tract of the same side, but he still holds to the opinion that pressure at the crossing accounts for some of the homolateral degeneration.

Redlich in 1897[76] made some investigations into the course and termination of the pyramidal fibres in the brain and cord in cats. In four cats he extirpated the motor region of the left cerebral hemisphere, and in one the motor region on both sides. He used the method of Marchi, having previously hardened the tissue in a mixture of Müller's fluid and 2% formaline. His results agree for the most part with those of previous workers. In sections through the upper parts of the mid-brain there was much degeneration scattered throughout the crusta except at the lateral margin which was free from degeneration. In sections at a lower level this non-degenerated area was seen to extend more towards the middle line along the anterior border of the crusta, so that the degenerated area was bounded antero-laterally by a non-degenerated area. In the pons and medulla this non-degenerated area had disappeared, and all the pyramidal bundles were thickly studded with degenerated fibres. At the decussation some fibres could be traced passing from the degenerated pyramid to the crossed pyramidal tract of the same side. He says that Rothmann is probably wrong in supposing this to be due to pressure. These homolateral fibres could be traced to the lower end of the thoracic region, and he says that they did not diminish in number from above downwards which seems somewhat difficult to understand. He supports Monakow in supposing that the fibres of the pyramidal tract do not end directly in relation to the cells of the anterior cornua of the spinal cord.

Hoche (77) in 1898 was able to apply the Marchi method to the study of the degenerations following unilateral motor lesions in two fatal cases of hemiplegia. He found degeneration in the middle portions of the crusta only, while the most mesial and lateral portions were free from degeneration. The degenerated fibres situated most laterally in the crusta became a separate bundle in the pons which could be traced down through the median fillet in the pons and upper part of medulla oblongata. Fibres from this bundle were seen to pass to the nuclei of the 7th and 12th cranial nerves on both sides most crossing the median raphe to the nuclei of the opposite side. He was also able to trace fibres from the degenerated pyramid to these same nuclei on both sides, showing that there are two distinct paths through which the 7th and 12th nerves may be thrown under the influence of the motor cortex. In the cord he states that he was able to trace degenerated fibres from both lateral pyramidal tracts into the grey matter of the anterior horns, and from the direct pyramidal tract also he could trace fibres passing into the grey matter of the anterior horns of both sides but mainly of the opposite side.

Dejerine and Long (78) in 1898 recorded five cases of cerebral hemiplegia - some right, some left, and as the age of the lesions ranged from 20 days to 2 months, all were suitable for the method of Marchi. The results of their examination of the brain and cord they summarise somewhat as follows:- The substantia nigra receives from the crusta numerous fibres which arborise round its cellular groups. The fillet (ribbon of Reil) receives deep and superficial fibres from the crusta, and also some fibres from the pyramidal tract as it passes through the pons, and these three sets of fibres rejoin the pyramid in the medulla. These they call aberrant peduncular and aberrant pontine fibres. They go on to say that "Contrary to what has been stated by Hoche, we have not been able to trace any degenerated fibres to any of the motor nuclei of the cranial nerves" and "we have obtained the same negative results for the degenerated pyramidal fibres in the spinal cord which we have never been able to follow to the cells of the anterior horns". . . "In the grey substance of the pons the very fine and very numerous granules which we have observed in two of the cases indicate a degeneration of collateral and terminal fibres at this level, and this fact explains to us the atrophy of the grey substance of the pons which one sees in old degenerations of the crus cerebri."

Romanow (79) in 1898 made experiments on dogs. He localised the cortical centres of the cranial motor nerves, and then ablated the particular centre with a sharp spoon. After from 20 to 30 days the animals were killed and the medulla and pons stained by Marchi's method. He traced the degenerated fibres down through the internal capsule, crusta, pons and medulla to the level of each of the nuclei, and at these levels degenerated fibres could be seen passing off backwards and crossing the middle line to the other side. In each case the fibres began to pass off a little above the level of the upper end of the nucleus in question (5th, 7th and 12th) and continued to pass off until a little above the level of the lower end of the nucleus. In the case of ablation of the cortical centre for the 7th nucleus degenerated fibres were traced close up to the nucleus, but in the case of the 5th and 12th they could not be traced quite up to the nuclei. In the 5th and 7th degenerated fibres could also be traced going to the nuclei of the same side.

5. METHOD of von GUDDEN. Lastly there is what might be termed the Atrophic or Non-developmental Method first employed by von Gudden (80) in 1872. This consists in removing from a newly born animal certain parts of the central nervous system, and allowing the animal to live, if possible, until it has reached the adult stage, or at least several months. It is then killed, and the parts which have remained undeveloped as a result of the operation are held to be directly connected functionally with the part removed in early life. v. Gudden and v. Monakow have been the chief workers along these lines. In 1872 Gudden removed the frontal area of one cerebral hemisphere in rabbits and dogs one day after birth. He allowed them to live for several months and then on killing them found that the corresponding pyramid was atrophied or non-developed. From this he concluded that the fibres which go to make up the pyramids have their origin in the anterior part of the cerebral cortex.

Monakow (81) in 1884 experimented in a similar way on two cats and two rabbits. He found atrophy of the corresponding anterior pyramids in medulla and pons and of the crossed pyramidal tract in the cord. He also observed atrophy in the grey matter of the corresponding optic thalamus and in the substantia nigra of the mid-brain of the same side, but he emphasises the fact that he could distinguish no difference between the two anterior cornua of the cord - the cells and grey matter had quite a normal appearance on the two sides, whereas on the side of the cord opposite to the cortical lesion the grey matter in the region of the processus reticularis or lateral horn was markedly atrophied. From this he concludes that the pyramidal fibres are directly connected with the grey matter in the lateral horn and not directly with the anterior cornua of the spinal cord. The conclusions which he arrived at, at that time, have been borne out by the results of much work done subsequently, and the whole matter is gone into very fully in an extensive article (82) published by him in the Archiv. für Psychiatre for 1895.

The view taken by most neurologists and supported by the observations of Mellus, Hoche, Romanow and others is, that there are only two sets of neurones on the motor path, whereas there are at least three on the sensory path. The advocates of this view teach that the pyramidal fibres, either by means of collaterals or of terminal fibres, form synapses around the cells of the cranial motor nuclei and of the anterior cornua of the spinal cord. Those fibres which end in relation to the cells of the cranial motor nuclei leave the pyramidal bundles in the pons and medulla, and crossing the median raphe either as single fibres or in very small bundles arborise around the cells of the nuclei of the opposite side, a few passing to the nuclei of the same side. The fibres destined for the anterior cornual cells of the spinal cord cross the middle line at the pyramidal decussation in the lower part of the medulla oblongata, and running down the crossed pyramidal tract of the opposite side of the cord, eventually arborise round the cells of the anterior horn of that side. A few, however, (homolateral fibres) do not cross in the decussation, but run down the lateral pyramidal tract of the same side to end in a similar way on that side. Thus, the motor nuclei and the anterior cornual cells of both sides are related to one cerebral hemisphere.

Monakow stands alone in opposing this view. He believes that there is an intermediate neurone between the pyramidal fibres and the lower motor neurones. He states that he has never been able to make out any direct connection between the pyramidal fibres and the anterior cornual cells, but that, instead of passing to the anterior horn, they pass to the processus reticularis near the lateral horn and end in relation to cells in this region. In this statement he has been recently supported by Schäfer (83) who finds that numerous fibres from the pyramidal tract in the monkey pass into the base of the posterior horn, and that none can be traced to the anterior horn. Monakow is of the opinion that in all probability an intermediate neurone is interposed between the ending of the pyramidal fibres in this region of the cord, and the cells of the anterior cornua, and that through these neurones impulses pass from the pyramidal fibres to the cell bodies of the lower motor neurones. At the present moment, the question to be answered is, which of these two views is the correct one, and it was with the object of throwing some light upon this matter, if possible, that the work recorded in the following pages was undertaken.

PART II. METHOD and RESULTS of RESEARCH.

In that part of the research the results of which are contained in this thesis sixteen cats and two monkeys were experimented upon, and in all these an attempt was made to divide the projection fibres arising from the left motor cortex in its whole extent. In other cases, in animals of the same species, partial motor lesions were made, but all the material has not yet been examined, and of these the results will be given later when the whole research is completed. In one case Professor Schäfer kindly placed at my disposal the brain and spinal cord of a dog in which he had, in the course of another investigation, made a lesion in the left motor cortex. I examined the secondary degeneration following from the lesion, and have given the results here.

OPERATIVE PROCEDURE. In every case the animal was fully anaesthetised with ether before the operation was begun, and was kept under the influence of the anaesthetic until it was completed and the wound closed and dressed. It was placed face downwards on a flat copper vessel containing warm water, and the room in which the operation was performed was always kept warm. This is an important

* point, more especially in the case of monkeys, as these animals are liable to suffer severely from the shock of the operation if it be performed in a cold room. The hair was cut short and then shaved off the left side of the skull. The skin was thoroughly washed with soap and warm water, and finally with 1 in 20 carbolic lotion. A rectangular-shaped incision was made through the integument, and a skin flap reflected downwards. Between the flap and the (possibly septic) hairs of the ear and side of face was placed some cotton wool or gauze, previously boiled and soaked in 1 in 20 carbolic. The bone was bared by scraping the muscles and fasciae from their attachments, and a small trephine opening was then made through the bone as nearly as possible over the area of the brain which it was desired to expose, and, if necessary, this opening was enlarged with bone forceps after the dura mater had been detached from the bone with a blunt-pointed probe or "finder." Very frequently, especially in the case of cats, there was much bleeding at this stage from the diploe, which in the skull of this animal is very thick, and this was arrested by soaking some sterilised cotton wool in a 5% solution of calcium chloride (warm and sterilised) and applying this with pressure to the face of the bone. When

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In each of the sixteen cats used, the lesion was practically the same, so that a description of one will suffice for all. It was confined to the left cerebral hemisphere, the object being to divide all the projection fibres arising from the motor cortex in their passage through the corona radiata, and if possible not to injure the corpus striatum, or, more especially, the optic thalamus. After all the bleeding from the diploe had been arrested and the dura mater reflected, sheathed platinum electrodes were applied to the anterior portion of the cortex, and the motor area localised by stimulation with a fairly weak faradic current. Without going into details, this was found to be situated in the sigmoid gyrus (around the crucial sulcus) and the anterior portions of the 1st, 2nd and 3rd convolutions (see photo). In the earlier operations until some practice had been gained, a formol-hardened brain was kept at hand in order that the convolutions and fissures might be the more easily identified. Having localised the area in this way, a fine blunt-pointed bistoury was pushed through the grey to the depth of about $\frac{3}{4}$ inch into the white matter close to the supero-mesial border of the hemisphere and about $\frac{1}{4}$ inch behind the posterior limit of the motor area; it was then carried outwards across the anterior portions of the 1st, 2nd and 3rd convolutions almost to the lateral border of the hemisphere, and in this way a deep incision was made cutting across all the motor fibres from the left hemisphere. The depth of the incision was always gauged on a formol-hardened brain before the knife was pushed into the living brain, and care was taken to avoid injury to the large vessels at the base. After the bleeding had stopped completely, but not until then, the dura was replaced and the skin wound closed with horse-hair sutures. It was then covered

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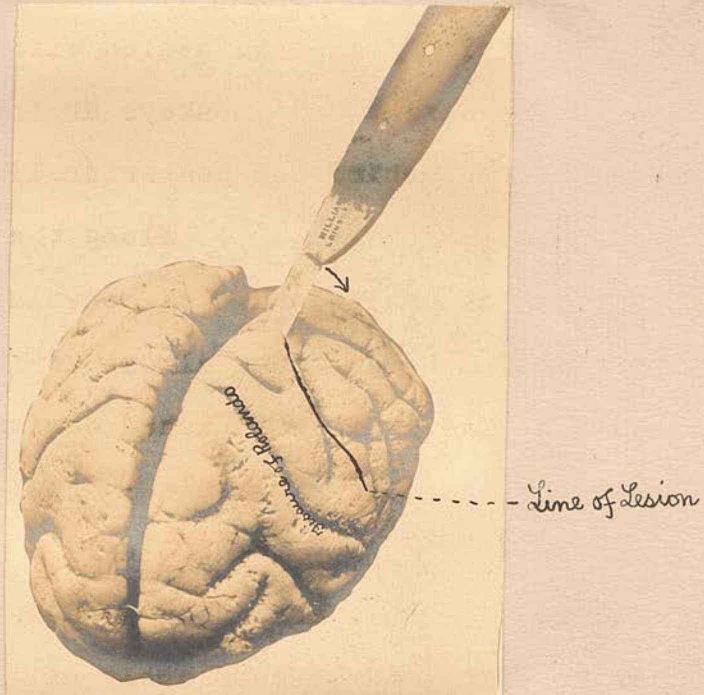


Photograph of Brain of Monkey to show how the lesion was made.

with antiseptic gauze and sealed with collodion.

In the case of the monkeys an incision was made, as in the cat, behind the posterior limit of the motor area on the left side, i.e. along the posterior border of the ascending parietal convolution from the supero-mesial border down almost to the fissure of Sylvius. The knife was pushed downwards and forwards into the corona radiata in a slanting direction, and in this way the whole left motor area was "under-cut." This method of "under-cutting" the motor area instead of completely extirpating it was adopted in order to avoid as far as possible any serious functional disturbance of the hemisphere— vascular or mechanical, with a view to determine the effects produced upon sensation by a purely motor lesion. In every case the wound healed by first intention.

The animals were allowed to live for a period ranging from a fortnight to five weeks after the operation, during which time the symptoms which they exhibited were carefully observed and noted down. They were then killed by an overdose of chloroform, the brain and spinal cord was carefully removed in each case, and those parts which were to be examined for degeneration were put into Müller's fluid, the rest being kept in 5% formol. In the later cases the whole brain and cord was fixed in 5% formol, but for Marchi's method fixation in formol was found to give not very satisfactory results.

HISTOLOGICAL TECHNIQUE. The method most frequently used, and finally adopted as better than any other, was that of Marchi, unmodified. This method, which will be found described in detail in either of the references given,[62] [91] is as follows:- After partially hardening the brain or cord in Müller's fluid or a 2% potassium bichromate solution for ten days, it is cut into thin slices - not more than 1/16 or 1/8 inch thick - and placed in a mixture of

Müller's fluid	2 parts	Marchi's solution.
1% Osmic Acid	1 part	

for other ten days. There must be excess of fluid-not less than twenty times the volume of the tissue. A ground glass stoppered bottle must be used perfectly air-tight to prevent evaporation of the osmic acid, and it must be kept in the dark to prevent its decomposition. After being left from ten to twelve days in Marchi's solution (if kept longer they tend to become brittle) the pieces of tissue are removed, when they will be found to be quite black, washed in several changes of water for twelve hours, then put into 75% alcohol, carried up the alcohol-xylol-paraffin series, embedded and cut in paraffin. No subsequent staining is needed; the myelin of those nerve fibres which are in the process of degeneration is rendered black while the normal nerve fibres are unstained or have a faint yellow colour due to the Müller's fluid.

Quite recently Halliburton and Mott (84) have submitted a "chemical explanation of the Marchi reaction." They state that during the process of degeneration of nerve tissue the phosphorised fat (lecithin) of the myelin becomes converted into a fat containing no phosphorus (ordinary stearin) and it is this latter which is stained black by the osmic acid. Lecithin (contained in normal myelin) is a phosphorised fat with choline as a base. In the process of degeneration the lecithin takes up a molecule of water and then splits up into choline, phosphoric acid and ordinary fat, the choline and phosphorus (in the form of a salt) being excreted.

The great disadvantage of this method is that in the above mixture the osmic acid has very little penetrating power, and for this reason the tissues have to be cut into very thin slices, otherwise the centre will not be stained, and this is a great drawback, especially when it is necessary to make serial sections, as much tissue is lost in the process of paring the ends.

With a view to increase the penetrating power of the osmic acid, Dr David Orr (85) has used as a substitute for Marchi's fluid a mixture of Acetic and osmic acids - 1% acetic acid 1 part)
) Orr's fluid.
1 % Osmic acid 4 parts)

The tissues previously hardened in Müller's fluid are cut into slices which may be twice as thick as when Marchi's fluid is employed, and placed in Orr's solution for ten days, after which time they are removed, dehydrated, &c., and cut either in paraffin or celloidin.

In order to increase the rapidity of action of the osmic acid (but not its penetrating power) Vassale (86) added to Marchi's solution a little nitric acid. - Vassale's fluid consists of :

1 % Osmic acid	1 part	)
Müller's fluid	3 parts	)
Strong Nitric Acid (20 drops to each 100 c.c. of fluid)		)

When this solution is used Vassale states that the tissues are ready for embedding in 4 to 5 days.

I have tried both these methods, but in my hands, at all events, neither of them has been very successful.

Redlich (76) in 1897 used a mixture of Müller's fluid and 2% formol, instead of Müller's fluid alone, for fixing the tissue previous to its immersion in

Marchi's fluid, and recently I was led to use 5% formol alone. The advantages claimed for formol fixation were, 1. That it saved time - 5 days being sufficient for complete fixation by formol, while 10 to 12 days are necessary when Müller's fluid is used. 2. That it renders the general ground or unstained portion of the sections whiter, and this is more suitable for photography. 3. That it renders the nervous tissue much firmer than Müller's fluid, so that one is enabled to cut the brain and cord into the thin segments necessary for osmic acid penetration with greater ease and exactness. On examining sections from material previously fixed in formol, I found that the staining was often very uncertain, and that frequently the coarser degenerated fibres had dropped out of the section, leaving, instead of a large black dot, a round hole. After having to a certain extent spoiled the material from several of my most important experiments, I abandoned this method and returned to the original Marchi method which in my experience is better and more reliable than any of its so-called improved modifications. I have obtained the best results from either old fluid (i.e. fluid which had been used over and over again), to which a little fresh osmic acid was added from time to time, or by using Marchi's solution prepared from Müller's fluid in which some brain tissue had been immersed for several months previously. Either of these, I am convinced, will reveal fine degeneration where the freshly prepared Marchi fluid will fail to do so.

After being cut in paraffin, the usual procedure is to float the sections out on warm water, either in a tray or on the slide in order to remove the folds in the paraffin and to fix the section to the slide. After this, the section has to be thoroughly dried either in an oven at a temperature of 35° C. for at least half-an-hour, or at the room temperature overnight. I found that in the case of such a compact tissue as the brain or spinal cord, this floating out on water was not necessary. The sections were laid on the slide after being cut, and then the paraffin was at once dissolved off by xylol. After all the paraffin had been removed, the section,(or sections, several being mounted on the same slide) floating in a pool of xylol,was placed in position, the xylol was drained off at one end by a strip of blotting paper, some thick Canada balsam was placed on a cover-glass, and then,when the section was just on the point of becoming dry, the cover-glass was inverted and placed on it. When most of the xylol had been removed by evaporation, the section did not shift its position on the slide when the cover-glass was applied. This was found to save much time, and, in my opinion, to give far better results. The section was much more transparent, and this was a great advantage, as it enabled one to cut and examine very thick sections in which collaterals and branching fibres which happened to be running obliquely could be traced for a much greater distance than in thin sections. All the sections were cut with the Cambridge Rocking-Microtome.

RESULTS of EXPERIMENTS - ANATOMICAL and PHYSIOLOGICAL. The method adopted in presenting the work done is as follows:- A record of each case was kept in which was noted down the details of the operation at the time when it was performed, the symptoms, if any, which followed as the result of the operation at the time when these were observed, and the naked eye appearances presented by the lesion when the animal was killed. In the description of the experiments these notes, after some editing and curtailing where necessary, are practically reproduced. The secondary degenerations which followed the lesions are described in a few typical cases from each set of animals, and in the rest, in order to save repetition as far as possible, only those points in which they differ from the types selected are mentioned. Sections taken at different levels from the brain and spinal cord are described and illustrated by pen and ink sketches in the notes of the animal to which they belong. The degenerated fibres are stained black by the osmic acid and stand out sharply against the white or pale-yellow unstained ground of the section. I spent much time in attempting to take photo-micrographs of the sections, but I must confess that my efforts have not been very successful. Failing myself, I consulted Mr Richard Muir of the Pathological Department, who is an expert photographer, and he assured me that nothing could be more difficult than to obtain a photograph from a Marchi stained specimen which would at all do it justice, especially a low-power view from thick sections such as I had purposely cut in order the better to be able to trace collaterals or branching fibres. Instead, then, of presenting photographs of them, I have submitted the specimens themselves, and would respectfully ask the reader to examine these specimens, preferably under the low power, from 40 to 50 diameters being the most suitable magnification.

The mode of testing the motor and sensory symptoms which followed from the operation was as follows:- If the animal were tame and quiet, it was taken out of the cage and allowed to move about the room when its general attitude and manner of walking were observed. In the case of monkeys their ability to climb up the wire netting of the cage was noted. To test voluntary power in the arms, the animal (monkey) was offered a small piece of banana or apple, or, best of all, a few currants were placed upon the floor within its reach and its ability or inability to take or pick up these was noted. In the case of the hind limbs, the animal was lifted up by grasping it at the back of the neck with one hand and placing the other hand under the chin to prevent it biting, and then swung towards the wire netting of the cage or dropped suddenly towards (but not to) the floor: if the animal had the power of voluntarily moving its limbs both were extended towards the cage or floor: if voluntary power were absent, then there was no such movement. With an animal suspended in this way, the paralysed limb hangs pendulous while the nonparalysed limb or limbs are usually drawn up somewhat. Voluntary power is much more easily tested in the monkey than in the cat, but when the latter is suddenly dropped towards the floor (on all fours) there may be no movement of the non-paralysed limb or limbs as a whole, but always the toes are extended and spread out as the foot approaches the floor. No such movement of the toes is observed in the paralysed limb.

To test the grasping power (in monkeys) a small stick or, preferably, the observer's finger was held out to the animal, and its power of hanging on to any object which it had seized, such as the wire netting of the cage was also noted.

In testing general sensibility, the part to be examined was touched or stroked lightly with a needle at the end of a long stick, while the animal's attention was attracted by another person so that it might not see that it was being touched. If sensation were not impaired, the animal looked round and withdrew the limb or indicated by some gesture that it felt the touch. To test whether pain was felt, it was pricked with the needle. The plan generally adopted was to test for pain first, and then it was found that after the animal had been rendered apprehensive by a prick of the needle, it responded much more readily to a simple touch.

The "clip-test" introduced by Schiff, and so much relied on by Mott[50] and others, was also employed, but, as pointed out by Schäfer,[87] it is entirely misleading, and want of response to the clip-test indicates motor rather than sensory paralysis. It consists in taking hold of the skin of the limb with a strong steel clip while the animal does not see what is being done. An attempt will be instantly made to remove a clip, so applied to a sound limb, while, if the limb is paralysed, no notice may be taken of it. Often it was found that an animal would respond to a simple touch while it took no notice of a strong clip as applied above to a paralysed limb. To quote from Schäfer's paper:- "The reason why the clip is not noticed upon the paralysed limb, while it is usually instantly remarked and removed from a sound limb, cannot therefore be connected with the loss of tactile sensibility, but must be connected with the loss of motility. It is in all probability the constantly occurring imperceptible muscular twitching in the sound limb which renders the pressure of the clip less uniform and makes the animal conscious of its presence." In examining as to whether the sensations of heat and cold were affected, the animal was suspended in a sling-jacket, and when it was perfectly quiet a vessel containing hot or cold water was brought up underneath it until the fingers or toes dipped into the water. If sensation was present the limb was withdrawn, or if there was voluntary paralysis of that limb the animal indicated, by struggling or otherwise, that it felt the hot or cold water. It was found that in every case the animal responded when hot water was applied to the foot, but on the paralysed side sensation was often delayed for a surprisingly long time, and it was deemed advisable to make more accurate observations on this point. The water was heated to the same temperature in each case (57° C.- unpleasantly hot for one's own hand but not hot enough to scald) in order to have a standard of comparison, and the time that elapsed between the immersion of the foot and the response of the animal was noted by means of a seconds vibrating pendulum. The knee-jerks were tested in the usual way. The temperature of the rectum, axilla, auticubital fossa, groin and popliteal space was taken from time to time, and the condition of the pupils and of visional sensation, more especially with regard to hemiopia was also noted. Lastly, the animal was weighed at regular intervals to test the effect of the operation on its general condition. The results of each examination were recorded on a chart at the time when the observations were made, and these were preserved along with the notes of the case. Exact copies of these charts are reproduced here, and from these the symptoms resulting from the operations can be summarised in a few lines.

When the animal was killed, and again after the brain had been partially hardened in 5% formol or

Müller's fluid, the position and extent of the lesion was examined so as to be accurately located, and in as many cases as possible photographs of the brain were taken before it was cut up and placed in Marchi's solution. In these photographs, which are presented, along with the Notes of the cases, the superficial area of the brain, to which the dura mater had become adherent after the operation, is shown, and also the depth to which the gross effects of the lesion had extended into the corona radiata. To the naked eye the latter was visible as a reddish brown patch - due probably to blood extravasation.

In the notes of the cases: 1. the position and extent of the lesion will be stated very briefly, no lengthy description being needed when the photograph is given; 2. the symptoms resulting from the operation will be summarised from the chart records taken at the time of observation, and 3. the secondary degenerations which followed the lesion will be described in detail from sections taken at different levels.

Cat No. I

Physical Examination

Animal - Cat No. 1   12th day after operation.   Weight - 2·96 Kilos

	Right Arm	Left Arm	Right Leg	Left Leg		
Motor						
Voluntary power ---	absent	present	slight	present		
~~Grasping~~ " ----						
~~Hanging on~~ " -----						
Walking " -----	Holds right	hind leg stiff	- not easily	flexed: otherwise runs about the room quite freely.		
~~Climbing~~ " -----						
Sensory						
Reaction to touch ---	present	present	present	present		
" " prick ---	"	"	"	"		
" " clip ----	absent	"	"	"		
" " cold water -	at once	at once	at once	at once	Water temp. uncomfortably hot for hand	
" " hot " ---	" "	" "	slight delay	" "		
Reflex. Knee-jerk ----	not examined					
	Axilla / Ant. fos.	Axilla / Ant. fos.	Groin / Pop. Sp.	Groin / Pop. Sp.	Rectum	Room
Temperature ------	not taken					
State of Vision -----	no defect of vision					

General Remarks.- The dressing has been removed from the head and no one could tell from its appearance that anything had been done to this animal.

To face p. 64 in this order

Cat No. I

Weight on day before operation 3·12 Kilos.

Physical Examination

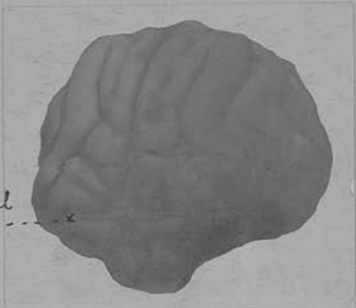
Animal – Cat No. 1 — 2nd day after operation — Weight – 3·01 Kilos

	Right Arm	Left Arm	Right Leg	Left Leg		
Motor						
Voluntary power ---	absent	present	absent	present		
~~Grasping~~ " ----						
~~Hanging on~~ " ----						
Walking " ----	Drags right hind limb and sometimes the right forepaw gets doubled up underneath it					
~~Climbing~~ " ----						
Sensory						
Reaction to touch ---	absent	present	slight	present		
" " prick ---	present	"	present	"		
" " clip ---	absent	"	absent	"		
" " cold water -	at once	at once	at once	at once	Water temp. uncomfortably hot for hand	
" " hot " ---	slight delay	" "	long delay	" "		
Reflex. Knee-jerk ---	not examined.				Rectum	Room
Temperature ------	Axilla 99·3; Ant. fos. 98·4	Axilla 99·6; Ant. fos. 98·8	Groin 99·2; Pop. Sp. 98·1	Groin 99·8; Pop. Sp. 98·9	100·2°F	76°F
State of Vision ----	No hemiopia and sees equally well with both eyes.					

General Remarks. – This animal has quite recovered from the shock of the operation, eats its food well and except for slight nothing appears to be wrong with it.

To face top of p. 64.

1



Photograph of brain of Cat No I (about natural size) – Observe area of surface of left hemisphere to which dura mater was adherent.

2

Same after a slice had been removed from anterior portion of left hemisphere. Observe lesion extending backwards into centrum ovale.

3

Same after another slice had been removed. Lesion has not extended so far back-wards as the plane of this section.

NOTES of CASES.

CAT No.I.

LESION. The fibres from the left motor cortex were severed by an incision into the white matter behind the motor area as already described. When the animal was killed the dura mater was found to be adherent to the anterior part of the left hemisphere as shown in photograph. The gross lesion in the corona radiata did not extend so far backwards as the caudate nucleus. This animal was killed 14 days after the operation.

SYMPTOMS during LIFE. There was voluntary paralysis in both right limbs. At first the animal was lame on the right side, but this was gradually recovered from. Tactile sensation was absent at first in the right fore leg and diminished in the right hind leg, but this was recovered from before the animal was killed. To cold there was response at once, but to heat there was some delay.

SECONDARY DEGENERATION.

Transverse Section of Midbrain through Anterior Corpora Quadrigemina, (See Fig.1, Specimen Cat No.I.1) The left crusta is uniformly studded with degenerated fibres over the whole area of its transverse section with the exception of a thin zone along its

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CAT No.I.

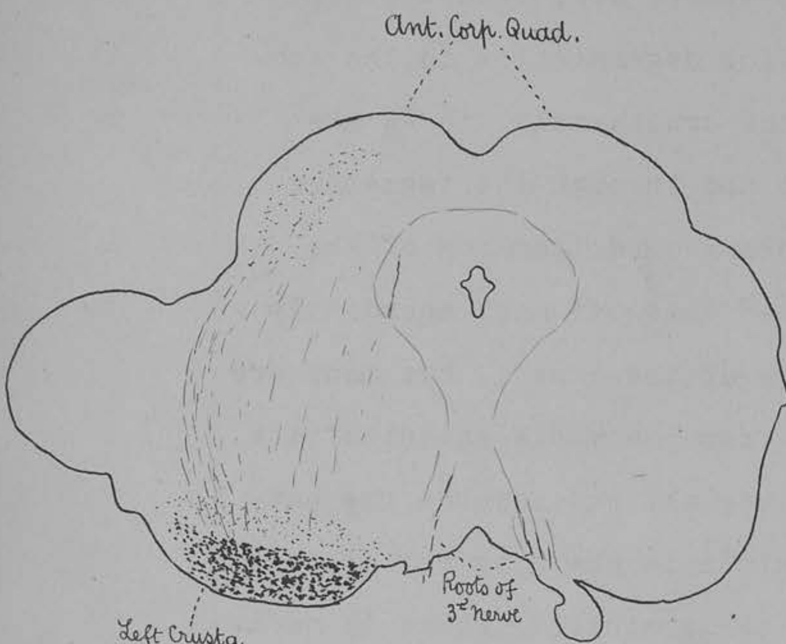

Fig.1 Cat No.I.

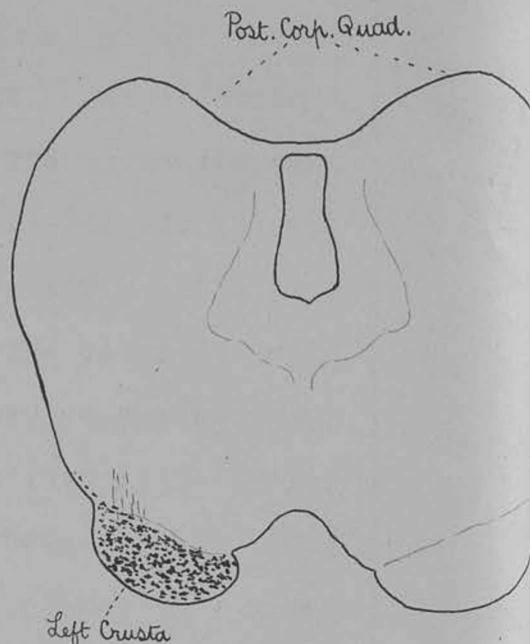

Fig. 2.

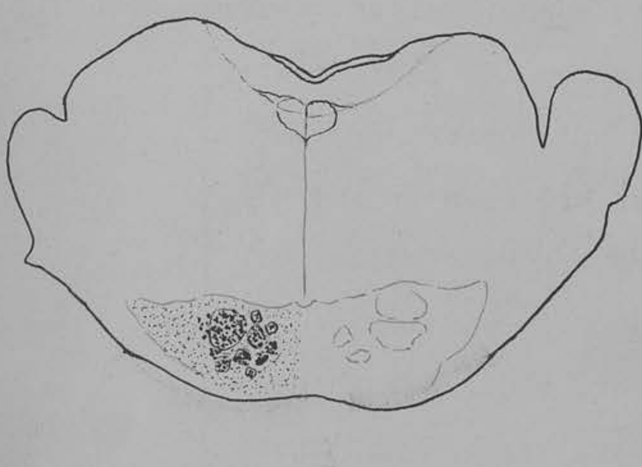

Fig. 3.

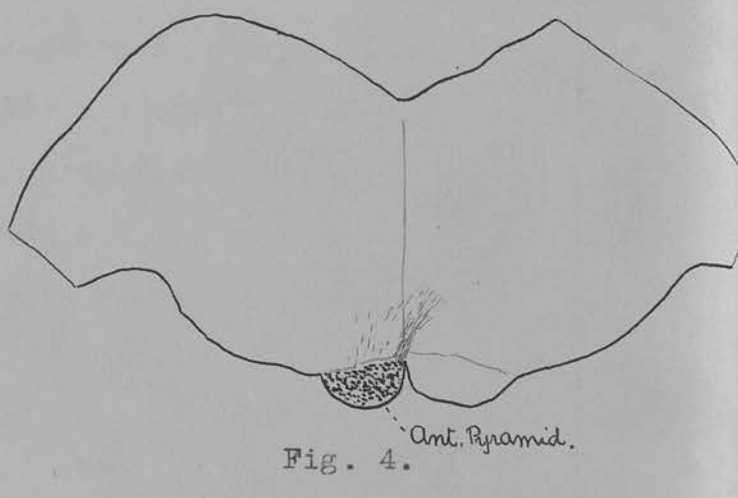

Fig. 4.

ventral border which is almost free from degeneration. There is much fine degeneration in the substantia nigra. From the crusta many fibres are seen streaming off into and through the tegmentum towards the anterior corpus quadrigeminum of the same side. These fibres come off most abundantly from the outer extremity of the crusta, but many are seen passing backwards from the whole extent of its posterior border, and they all run towards the anterior corpus quadrigeminum in the grey matter of which they can be seen to terminate: there is much fine degeneration in this grey matter. Those from the mesial extremity of the crusta pass backwards close to the central grey matter around the Sylvian Aqueduct, and one or two fibres pass through the lateral part of the grey matter, but all are directed towards the anterior corpus quadrigeminum. There is a small patch of degeneration in the central grey matter lying close to the left side of the Sylvian Aqueduct. Some black granules are seen in the emerging roots of the 3rd nerve and descending root of 5th on each side, and also in the bundles of Meynert's decussation on the left side; but these granules are deposited irregularly and not in interrupted lines, and do not represent degenerated fibres. A very few degenerated fibres are seen in the right crusta.

In sections from a slightly lower level degenerated fibres from the left anterior corpus quadrigeminum can be made out crossing the middle line to end in the grey matter of the right anterior corpus.

Transverse Section Upper Pons through Posterior Corpora Quadrigemina, (See Fig.2, Specimen Cat No.I.2) The whole left crusta, which is just passing into the pons, is degenerated. A few fibres pass backwards from its outer angle into the tegmentum, but they cannot be traced for any distance. No fibres can be seen passing backwards towards the posterior corpus quadrigeminum, and there is no fine degeneration in its grey matter. Very abundant fine degeneration is seen around the cells of the nuclei pontis which lie amongst the transverse fibres of the pons just in front of the degenerated crusta, and this is strictly limited to the side of the lesion. There is no degeneration in the central grey matter on either side.

Transverse Section through Middle of Pons, (See Fig.3, Specimen Cat No.I. 3). All the pyramidal bundles on the left side (side of lesion) are filled with degenerated fibres - coarse, medium and fine - and the degeneration invades to a slight extent the lateral portion of the mesial fillet. There is very abundant fine degeneration scattered amongst the cells of the nuclei pontis laterally, anteriorly and mesially to the pyramidal bundles; this fine degeneration stops abruptly at the median raphe, and none is visible on the opposite side. No degeneration, coarse or fine, is seen in the grey matter of the floor of the 4th ventricle.

Transverse Section Lower Pons, (See Fig.4, Specimen Cat No.I. 4). The left anterior pyramid (which appears smaller to the naked eye than the right) shows extensive and uniform degeneration. There are numerous fine dots scattered amongst the transverse pontine fibres which lie posterior to the anterior pyramids on both sides. From the posteromesial angle of the degenerated pyramid, a well-marked bundle of degenerated fibres passes off and immediately, crossing the middle line, disappears in the formatio reticularis of the opposite side. In addition to this well-marked bundle, a few fibres are given off from the whole posterior aspect of the degenerated pyramid; most pass backwards and inwards and crossing the raphe are lost in the reticular formation of the opposite side, but a few run directly backwards and disappear in the formatio reticularis of the same side. None of these fibres

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CAT No.I.

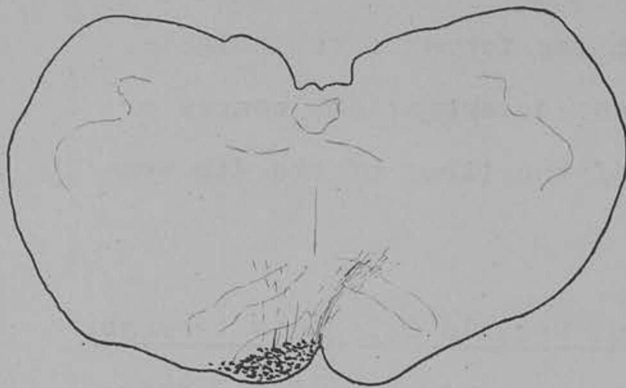

Fig. 5.

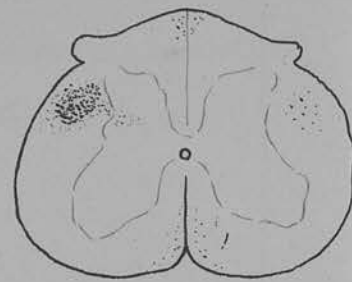

Fig. 8.

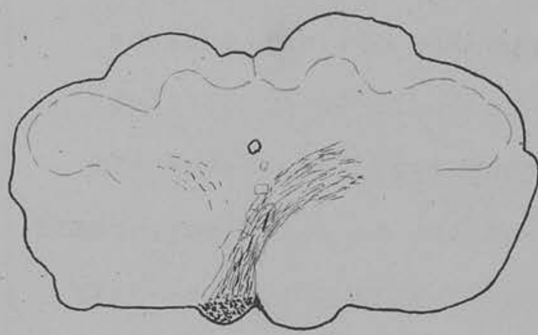

Fig. 6.

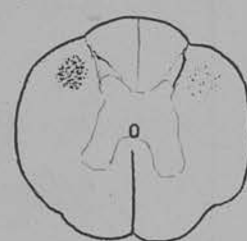

Fig. 9.

Fig. 7.

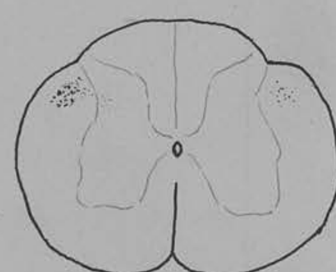

Fig.10.

can be traced far through the formatio reticularis. There is no evidence of any degeneration, coarse or fine in the grey matter of the floor of the 4th ventricle.

Transverse Section of Medulla Oblongata through Middle of Inferior Olivary Nucleus, (See Fig.5, Specimen Cat No.I. 5). The left pyramid is extensively degenerated as in the last section, and coming off from its postero-internal angle are a few degenerated fibres which cross the middle line in front, and passing through the opposite olivary nucleus, disappear in the formatio reticularis immediately behind that nucleus. One or two fibres come off from the posterior aspect of the degenerated pyramid and running directly backwards through the olivary nucleus of the same side are lost in the formatio reticularis behind it. In this specimen (some of the thicker sections) the root fibres can be very well seen coming from the hypoglossal nucleus and passing forwards to emerge lateral to the olivary nucleus. No degenerated fibres can be seen passing towards the hypoglossal nucleus on either side, and no fine degeneration is visible in these nuclei.

Transverse Section of Medulla Oblongata about Middle of Pyramidal Decussation, (See Fig.6, Specimen Cat No.I. 6). The left pyramid is studded with degenerated fibres, and a large bundle is seen to pass obliquely across the middle line interlacing with a similar bundle of undegenerated fibres from the opposite pyramid. At first it passes backwards close to the antero-lateral aspect of the central canal, and then it curves more lateralwards through the grey matter ending in the region of the base of the nucleus cuneatus of the right side. Some degenerated fibres (homolateral) are seen curving round towards the left side and running along with the decussated fibres from the right pyramid. A few black granules are seen in the funiculus gracilis on each side close to the middle line but none in the nuclei of these funiculi.

Transverse Section of Medulla Oblongata about lower extremity of Pyramidal Decussation, (See Fig.7 Specimen Cat No.I. 7). A narrow area of degeneration is seen bordering the anterior median fissure on the left side; this is all that remains of the left anterior pyramid. From the posterior extremity of this area, two or three small bundles of degenerated fibres cross the middle line. These bundles run at first backwards and then curve more outwards and passing through the grey matter join bundles of transversely cut fibres at the base of the substantia gelatinosa of Rolando and in the inner part of the lateral column of the opposite side which have decussated at a higher level. These fibres will form the right crossed pyramidal tract of the spinal cord at a slightly lower level. One or two homolateral fibres can be seen passing through the grey matter towards the crossed pyramidal tract of the same (left) side, but in this animal these homolateral fibres are not so abundant as in others to be described subsequently. A number of degenerated fibres (mostly coarse) are seen in the funiculus and nucleus gracilis on each side; and in the anterior column there are several large degenerated fibres. From this region on the left side, one or two fibres can be seen running towards the anterior horn, but not quite reaching it. These fibres last mentioned have not been mistaken for the nerve roots emerging from the anterior horn, which in some of the sections may also be seen containing fine black granules.

Transverse Section of Spinal Cord - 6th Cervical Segment, (See Fig.8, Specimen Cat No.I. 8). In the posterior portion of the right lateral column is seen a rounded area of degeneration abutting against the apex of the posterior horn but not reaching quite to the circumference of the section. From its mesial aspect many fibres cut somewhat obliquely can be seen streaming in towards the base of the posterior horn and processus reticularis, and there is a slightly greater amount of fine degeneration in the grey matter of these regions on this side than on the opposite side or in the anterior cornua. Symmetrical bilateral degeneration is seen in the columns of Goll, and the degeneration noticed in both anterior columns in the last section is now to be observed lying along the borders of the anterior median fissure; from this area of degeneration on the left side, one or two fibres can be seen passing into the anterior horn. In some of the emerging anterior nerve roots, many fine black granules are seen analogous to those observed in the roots of the third nerve, Uniformly scattered over the whole area of this section are many such granules, possibly due to debris deposited from the paraffin in which the piece of tissue was embedded, and for this reason it is difficult to be certain about the homolateral fibres in the area of the crossed pyramidal tract of the same side as the lesion.

<u>Transverse Section of Spinal Cord - Mid-dorsal Region</u>, (See Fig.9, Specimen Cat No.I. 9). The rounded area of degeneration occupied by the right crossed pyramidal tract is seen lying lateral to the tip of the posterior horn. It is considerably

smaller than in the cervical region, and only one or two fibres can be made out passing from its inner aspect towards the base of the posterior horn. The bilateral degeneration in the columns of Goll has disappeared at this level. Little else can be made out in this section on account of the precipitation which is scattered uniformly over its whole area.

Transverse Section of Spinal Cord - 2nd Lumbar Segment, (See Fig.10, Specimen Cat No.I. 10). The right (degenerated) crossed pyramidal tract occupies the same relative position as in the dorsal region; it is considerably smaller in area, and the degenerated fibres within the area are not so numerous. A few fibres can be seen running towards the base of the posterior horn. As in the other sections of the spinal cord the homolateral degenerated fibres cannot be made out with certainty because of the diffuse precipitation which has unfortunately occurred from some cause or other in the process of preparation.

Cat Nº II.

Physical Examination

Animal – Cat Nº II 2nd day after operation. Weight – Not taken before operation

	Right Arm	Left Arm	Right Leg	Left Leg	
Motor					
Voluntary power ---	absent	present	absent	present	
~~Grasping~~ " ----					
~~Hanging on~~ " ----					
Walking " ----	Animal lies on its right side in the cage and will not move voluntarily out of that position				
~~Climbing~~ " ----					
Sensory					
Reaction to touch ---	present	present	present	present	
" " prick ---	"	"	"	"	
" " clip ----	absent	absent	absent	absent	– Took no notice of clip on any of its limbs
" " cold water -	at once	at once	at once	at once	Water temp. about 60°F
" " hot " ---	slight delay	" "	slight delay	" "	
Reflex. Knee-jerk ----	not examined				
Temperature ------	Axilla / Ant. fos. — not taken	Axilla / Ant. fos. — not taken	Groin / Pop. Sp.	Groin / Pop. Sp.	Rectum / Room
State of Vision -----	No hemiopia or other defect of vision				

General Remarks. – This animal suffers from the shock of the operation much more than Cat Nº 1 did. It rotates its head towards the left – towards the lesion.

To face page 73 in this order.
Photos in front of these as they now lie.

Cat No. II

Physical Examination

Animal – Cat No. II   14th day after operation   Weight – not taken

	Right Arm	Left Arm	Right Leg	Left Leg		
Motor						
Voluntary power	absent	present	absent	present		
~~Grasping~~ "						
~~Hanging on~~ "						
Walking "	Walks	quite well	– can detect	no lameness		
~~Climbing~~ "						
Sensory						
Reaction to touch	present	present	present	present		
" " prick	"	"	"	"		
" " clip	"	"	"	"		
" " cold water	"	"	"	"	Water temp.	
" " hot "	at once	at once	at once	at once		
Reflex. Knee-jerk	not	examined			Rectum	Room
Temperature	Axilla / Ant. fos. (not taken)	Axilla / Ant. fos. (not taken)	Groin / Pop. Sp.	Groin / Pop. Sp.		
State of Vision	as before.					

General Remarks. –

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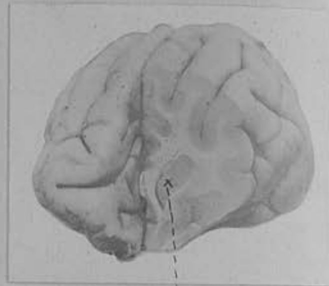
1

Left front view – surface

2

Lesion

3



Head of Caudate

CAT No.II.

LESION. This was exactly similar to that described in the last case. The accompanying photograph will show the part of the left hemisphere involved. On slicing away the hemisphere from before backwards, the gross lesion could be traced through the corona radiata as a brownish-red patch to, but not beyond, the head of the caudate nucleus. The animal was killed 16 days after the operation.

SYMPTOMS following OPERATION. There was motor paralysis in both right limbs which did not pass off. Tactile sensibility was not affected, but the animal for a few days after the operation did not respond to the "clip-test."

SECONDARY DEGENERATION.

Transverse Section Midbrain through Anterior Corpora Quadrigemina. (See Fig.1, Specimen Cat No.II. 1). All the crusta on the left side (side of lesion) shows scattered degeneration, except a narrow marginal area along its antero-lateral border, and a large number of degenerated fibres are seen passing out from the crusta into and through the substantia nigra and through the tegmentum. These fibres run backwards, and can be traced into the grey matter of the anterior corpus quadrigeminum of

To face p.74

CAT No.II.

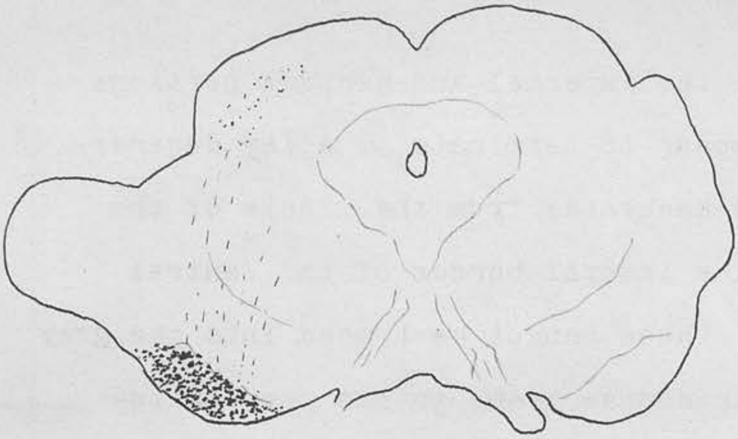


Fig. 1.

Fig. 2.

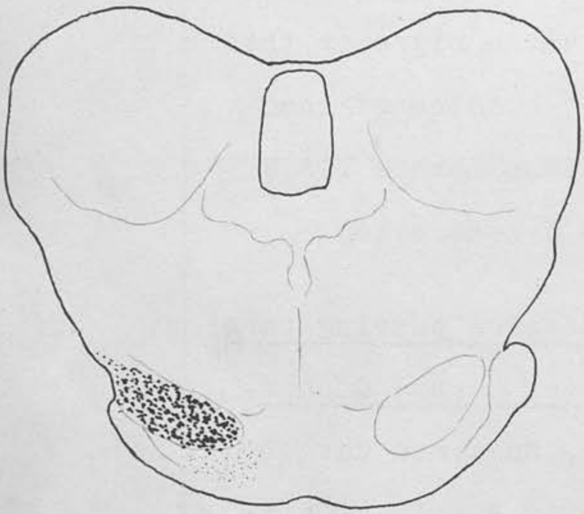


Fig. 3.

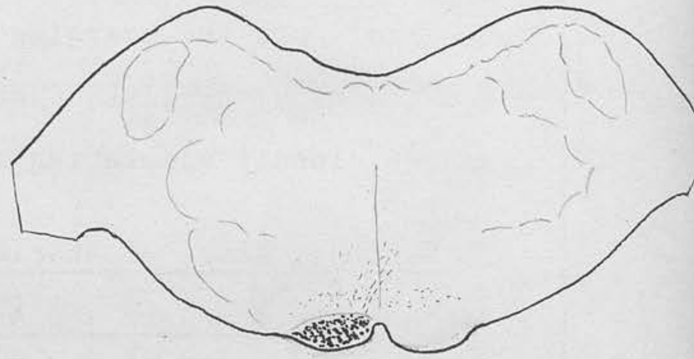


Fig. 5.

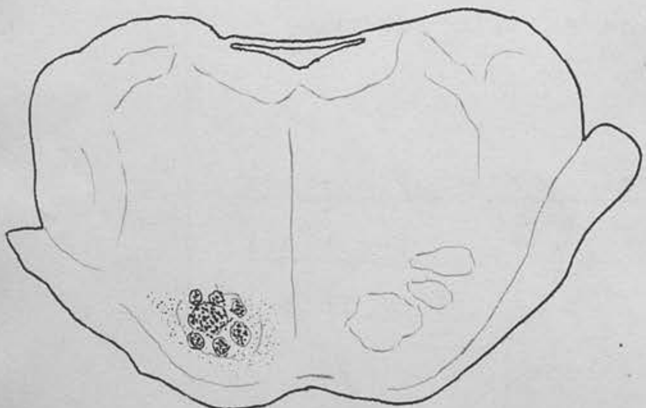


Fig. 4.

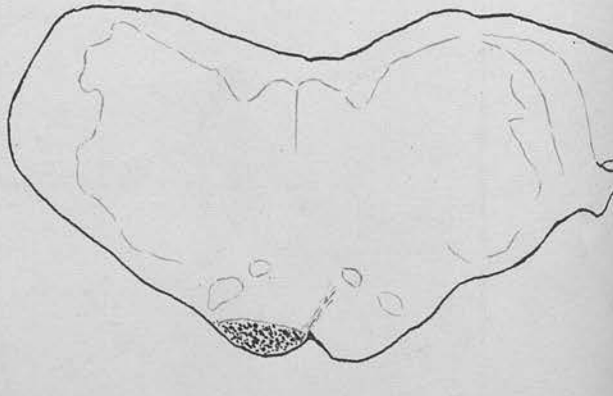


Fig. 6.

the same side in the external and central portions of which they appear to terminate. A few degenerated fibres pass backwards from the middle of the crusta towards the lateral border of the central grey matter, but these cannot be traced into the grey matter, and their course seems to run past it towards the anterior corpus quadrigeminum. There is a considerable amount of fine degeneration in the grey matter of the anterior corpus quadrigeminum, and a slight amount in the substantia nigra on the left side. In the emerging root bundles of the 3rd nerve on both sides, there are numerous black granules closely simulating true degeneration.

Vertical Antero-Posterior Section passing thro' the degenerated crusta and Anterior Corpus Quadrigeminum of same side, (See Fig.2, Specimen Cat No.II. 2) - indicated by red line in Fig.1. This shows the degenerated bundles of the crusta cut longitudinally, and from these fibres passing backwards and downwards towards the anterior corpus quadrigeminum.

Transverse Section Midbrain through Posterior Part of Anterior Corpora Quadrigemina - below origin of 3rd nerve, (Specimen Cat No.II. 3). This section presents the same appearance as section 1., except that the fibres running backwards towards the anterior corpus quadrigeminum are not so numerous at this level.

Transverse Section Upper Part of Pons passing through Posterior Corpora Quadrigemina, (See Fig.3, Specimen Cat No.II. 4). The pyramidal bundle on the left side shows uniform and extensive scattered degeneration over the whole area of its transverse section. Anterior and internal to this bundle, there is a considerable amount of fine degeneration amongst the cells of the nuclei pontis in this the upper region of the pons. One or two fibres are seen passing backwards from the outer angle of the degenerated crusta towards the posterior corpus quadrigeminum, but these cannot be traced for any distance into the formatio reticularis.

Transverse Section through Middle of Pons, (See Fig.4, Specimen Cat No.II. 5). The pyramidal bundles on the left side are markedly degenerated all over, and there is very abundant fine degeneration amongst the cells of the nuclei pontis on the same side amongst the transverse fibres of the pons, through which the pyramidal bundles run. No such fine degeneration is seen on the opposite side. One or two degenerated fibres pass backwards from the lateral pyramidal bundles on the left side through the trapezium into the formatio reticularis, but they cannot be traced for any distance. No degeneration is visible in the grey matter of the floor of the 4th centricle.

<u>Transverse Section Lower Pons, (</u>See Fig.5,Specimen Cat No.II. 6). (In the cat the anterior pyramids come to the surface in the lower levels of the pons.) Pyramid on left side is smaller in area than that on the right, and is filled with degenerated fibres. There are many fine black granules scattered amongst the transverse fibres immediately behind the pyramids on both sides, but most numerously on the left (degenerated) side. From the left pyramid, a few degenerated fibres run backwards and inwards, and crossing the median raphe are lost in the formatio reticularis of the opposite side.

<u>Transverse Section Medulla Oblongata through Upper Part of Inferior Olivary Nucleus,</u> (See Fig.6, Specimen Cat No.II. 7). The left anterior pyramid is slightly smaller than the right, and shows marked degeneration throughout its whole area. From its postero-mesial angle a small bundle of degenerated fibres come off, and immediately crossing the middle line can be traced passing through the opposite olivary nucleus into the formatio reticularis, where they soon disappear. No fibres can be seen

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CAT No.II.

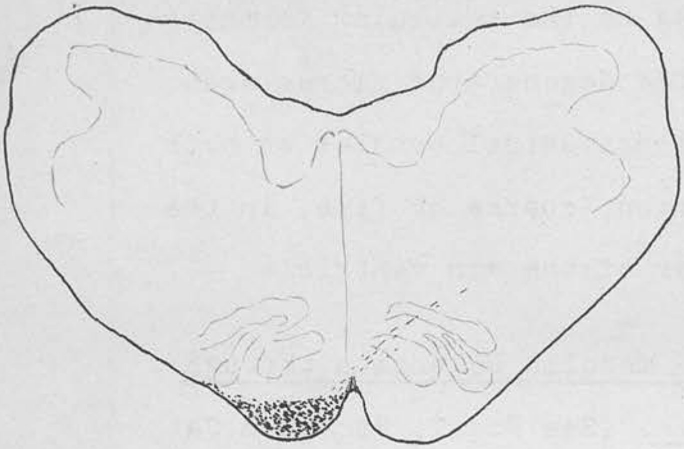

Fig. 7.

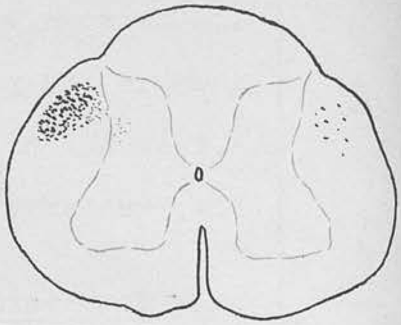

Fig. 10.

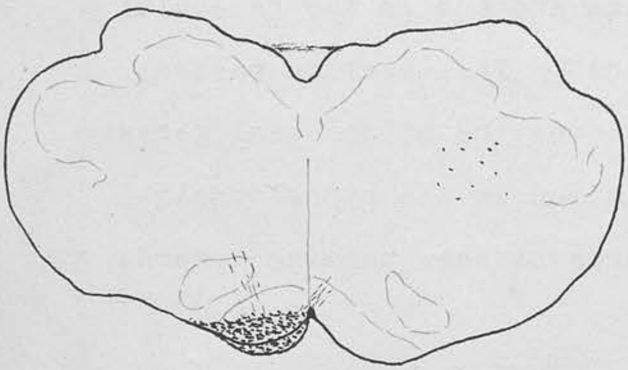

Fig. 8.

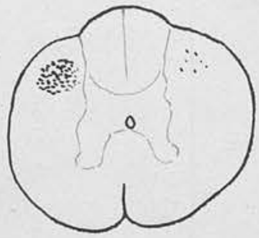

Fig.11.

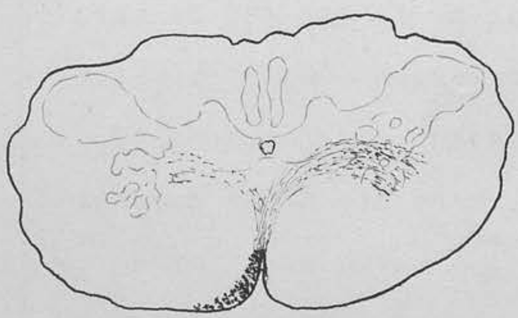

Fig. 9.

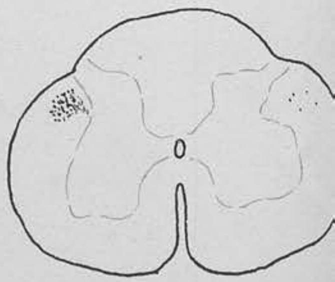

Fig.12.

in this specimen passing to the reticular formation on the same side. A few degenerated fibres are seen in the posterior longitudinal bundles on both sides, but no degeneration, coarse or fine, in the grey matter of the floor of the 4th ventricle.

<u>Transverse Section Medulla Oblongata through Middle of Inferior Olive</u>, (See Fig.7, Specimen Cat No.II. 8). The left pyramid is degenerated as in the last section, but very few fibres cross the middle line at this level: one or two run backwards through the inferior olive and end in the reticular formation of the same side. This section passes through the emerging roots of the hypoglossal nerve. There is no fine degeneration in the hypoglossal nucleus, nor can any fibres be seen passing towards it on either side.

<u>Transverse Section Medulla Oblongata through Inferior Extremity of Olive</u>, (See Fig.8, Specimen Cat No.II.9) The left anterior pyramid is degenerated as in other sections of the medulla, but no fibres can be seen passing to the reticular formation of the opposite side. Anterior to the substantia gelatinosa of Rolando on the right side, there are a few degenerated fibres transversely cut - these are fibres which have probably decussated at a higher level; they occupy the same relative position as the fibres

of the crossed pyramidal tract in the cord. Numerous fine black granules are visible amongst the external arcuate fibres going towards the restiform body on the right side, quite distinct from the coarse granules seen in the position of the crossed pyramidal tract just described.

Transverse Section of Medulla Oblongata about Middle of Pyramidal Decussation, (See Fig.9, Specimen Cat No.II. 10). The clear area in the centre of the section is due to faulty penetration of the Marchi fluid. The left pyramid, which is much diminished in area, is filled with degenerated fibres, and a large bundle can be seen crossing the middle line at the bottom of the anterior median fissure, at first running backwards and then curving more outwards through the grey matter, and ending at the base of the substantia gelatinosa of Rolando in fasciculi of similar fibres which have decussated at a higher level. A few fibres pass to the posterior part of the lateral column in front of the substantia gelatinosa, but the main mass has not yet reached the lateral column. A considerable number of degenerated fibres pass backwards from the left pyramid, and curve round towards the lateral column of the same side - these are homolateral fibres. There is a narrow marginal area of degeneration in the anterior part of the left lateral column.

<u>Transverse Section Spinal Cord - 7th Cervical Segment</u>, (See Fig.10, Specimen Cat No.II. 11.) The crossed pyramidal tract (degenerated) of the right side is seen as a rounded area and occupies a position similar to that described in Cat No.I. In some of the sections in this specimen, fibres can be made out streaming into the base of the posterior horn. A few degenerated fibres are scattered over a corresponding area on the opposite side (left-side of lesion) - these are homolateral fibres which have not decussated in the medulla.

<u>Transverse Section Spinal Cord through 2nd Dorsal Segment</u>, (See Fig.11, Specimen Cat No.II. 12). The crossed pyramidal tract is seen on the right side occupying the same relative position as in the last section, but considerably reduced in area. No fibres enter the base of the posterior horn at this level. A few homolateral fibres are evident in the left lateral column. Numerous black granules are scattered over the whole section in addition to the pyramidal fibres already mentioned.

<u>Transverse Section Spinal Cord through Lower Dorsal Region</u>, (Specimen Cat No.II. 13). This is

similar to the last section, except that the pyramidal fibres on both sides are fewer in number.

Transverse Section Spinal Cord through 4th Lumbar Segment, (See Fig.12, Specimen Cat No.II. 14). The degenerated crossed pyramidal tract is now considerably reduced in size on the right side, and a few fibres can be seen passing towards the base of the posterior horn; there is also a slight amount of fine degeneration in the grey matter towards which these fibres pass. Very few homolateral fibres are visible on the opposite side.

Cat No. III.

Physical Examination

Animal – Cat No. III — 16th day after operation. Weight – 2.63 Kilos

	Right Arm	Left Arm	Right Leg	Left Leg	
Motor					
Voluntary power ---	?	present	?	present	
~~Grasping~~ " ----					
~~Hanging on~~ " ----					
Walking " ----	No evidence of any lameness				
~~Climbing~~ " ----					
Sensory					
Reaction to touch ---	absent	present	present	present	
" " prick ---	present	"	"	"	
" " clip ----	absent	"	"	"	
" " cold water -	at once	at once	at once	at once	Water temp.
" " hot " ---	delay	" "	long delay	" "	
Reflex. Knee-jerk ----	slightly more marked on right than on left side				Rectum / Room
	Axilla / Ant. fos.	Axilla / Ant. fos.	Groin / Pop. Sp.	Groin / Pop. Sp.	
Temperature ------	Not taken				
State of Vision -----	as before.				

General Remarks. –

2 face p. 81 in this order.
Photo sheet between this & p. 81

Cat Nº III

Weight before operation 2·63 Kilos

Physical Examination

Animal – Cat Nº III   2nd day after operation.   Weight – 2·61 Kilos

	Right Arm	Left Arm	Right Leg	Left Leg	
Motor					
Voluntary power	absent	present	absent	present	
~~Grasping~~ "					
~~Hanging on~~ "					
Walking "	Both right limbs are weak and a slight push forwards causes it to fall towards the right side				
~~Climbing~~ "					
Sensory					
Reaction to touch	absent	present	absent	present	
" " prick	"	"	present	"	
" " clip	"	"	absent	"	
" " cold water	"	at once	"	at once	Water temp. uncomfortable for hand.
" " hot "	long delay,	at once	long delay,	at once	
Reflex. Knee-jerk	Brisk on both sides but most marked on left side				

	Axilla	Ant. fos.	Axilla	Ant. fos.	Groin	Pop. Sp.	Groin	Pop. Sp.	Rectum	Room
Temperature	not taken.									

State of Vision	No defect of vision.

General Remarks. –

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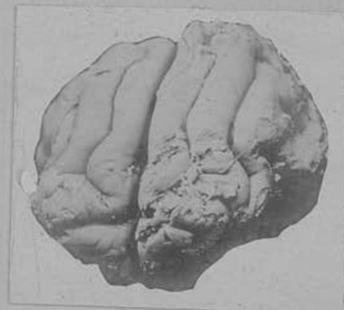

Photograph of Brain of Cat No III (about natural size)
(Seen from front and left)

CAT No.III.

LESION. Same as in the two previous cases.

SYMPTOMS. There was at first marked loss of voluntary power on the right side accompanied by sensory paralysis, but both were gradually recovered from. From the first both right limbs responded to the hot water test, although there was a long delay in each case. The knee-jerk seemed to be exaggerated on both sides for a few days after the operation, but later it was most marked on the right side. There was no evidence of hemiopia. The temperature of the limbs was not taken. This animal was killed 21 days after the operation.

SECONDARY DEGENERATION. In this case the whole brain was cut into slices and treated with Marchi's fluid, and from these coronal sections were made. It is very difficult in such large pieces of tissue to get good penetration of the osmic acid.

Coronal Section through Genu of Corpus Callosum. It passes through the head of the caudate nucleus on each side (slightly obliquely) and anterior part of optic thalamus, (See Specimen Cat No.III. 1.) The left internal capsule is filled with degenerated fibres, the inferior part containing fine fibres only. The corona radiata contains many degenerated fibres cut in all directions passing down towards the internal capsule, and many are also seen cut longitudinally passing through the corpus callosum to the other side; but there are none in the right internal capsule. No fine degeneration is visible in the caudate nucleus or optic thalamus.

Coronal Section through Anterior Part of 3rd Ventricle (slightly oblique), (See Specimen Cat No.III. 2.) The bundles of the internal capsule are studded with degenerated fibres transversely cut throughout its middle $^4/5$th. No fibres pass through the corpus callosum at this level, and there is no degeneration in the right internal capsule. A very slight amount of fine degeneration is present in the left optic thalamus. (Many of the black lines seen in this specimen indicate bloodvessels and not degenerated nerve fibres.)

Coronal Section through Middle of 3rd Ventricle. (See Specimen Cat No.III. 3.) This shows the left internal capsule degenerated as in last section, the upper or anterior bundles being free. No fibres pass through the corpus callosum. There is some fine degeneration in the grey matter of the optic thalamus on the left side.

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CAT No.III.

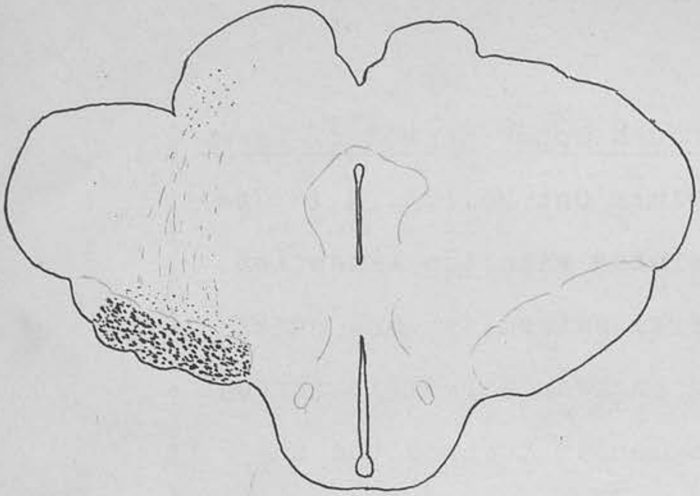

Fig. 1.

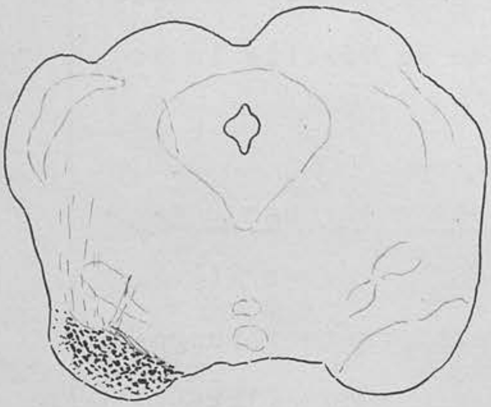

Fig. 2.

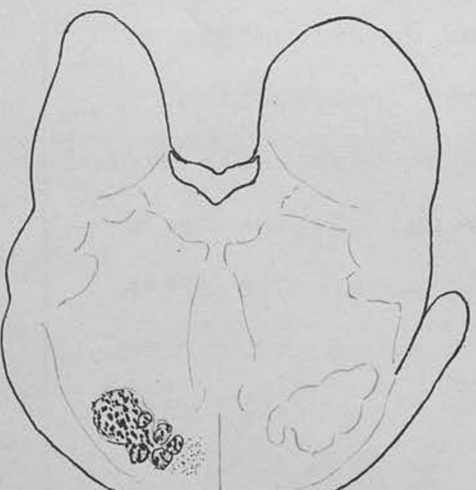

Fig. 3.

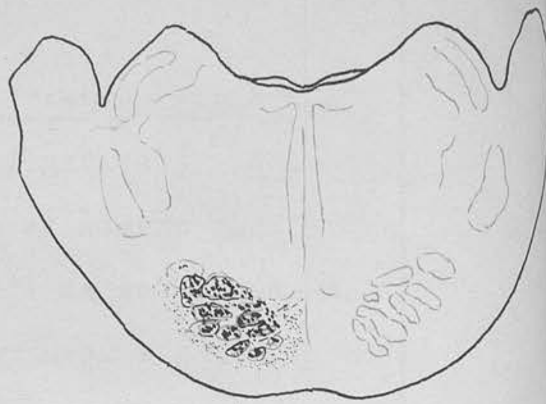

Fig. 4.

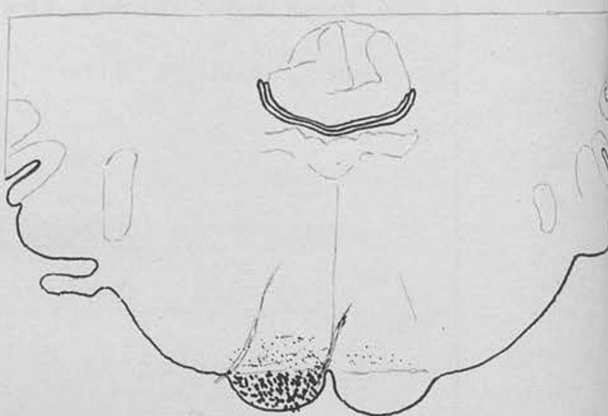

Fig. 5.

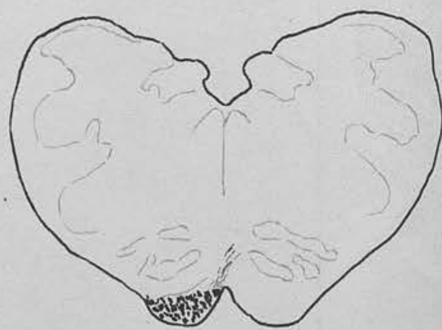

Fig. 6.

Transverse Section through Upper Region of Mesencephalon. (See Fig.1, Specimen Cat No.III. 4.) The whole left crusta is degenerated with the exception of a small area at its lateral extremity, and numerous fibres are seen running backwards from it through the substantia nigra and tegmentum towards the anterior corpus quadrigeminum of the same side, in the grey matter of which they appear to end. None are seen passing towards the central grey matter in this specimen, and no fine degeneration is visible in it on either side.

Transverse Section Mesencephalon through Lower Part of Anterior Corpora Quadrigemina. (See Fig.2., Specimen Cat No.III. 5.) The left crusta throughout contains thickly scattered degenerated fibres, except a narrow marginal area around its anterior border. Some fibres can be seen passing off backwards towards the anterior corpus quadrigeminum of the same side, as described in the last section; but these are not so numerous as at a slightly higher level. There is a slight amount of fine degeneration in the grey matter of the substantia nigra on the left side, but not so much as in the corresponding sections from the formerly described animals.

Transverse Section through Upper Part of Pons. (See Fig.3., Specimen Cat No.III. 6.) The pyramidal bundles on the left side are uniformly degenerated throughout their whole extent. There is a slight amount of fine degeneration scattered amongst the cells of the nuclei pontis mesial to the pyramidal bundles - this does not reach quite to the middle line, and none is visible on the opposite (right) side. No fibres are seen passing backwards from the degenerated bundles.

Transverse Section through Middle of Pons. (See Fig.4., Specimen Cat No.III. 7.) This presents the same appearance as the last section, except that at this level there is fine degeneration in the region of the nuclei pontis on the lateral and anterior as well as on the mesial aspect of the pyramidal bundles. No degenerated fibres are seen elsewhere in the section.

Transverse Section through Lower Part of Pons at level of exit of 6th and 7th Nerves. (See Fig.5 Specimen Cat No.III. 8.) The left anterior pyramid is studded with degenerated fibres over its whole area, and posterior to it, scattered amongst the transverse fibres, are seen several small degenerated bundles (pontine bundles) which will join the anterior pyramid at a lower level. One or two fibres are seen crossing the middle line to disappear in the reticular formation of the opposite side. No fine degeneration is visible anywhere in the grey matter. The 6th nerve emerges just lateral to the pyramid on each side, and the bundles of the 7th more posteriorly.

Transverse Section Medulla Oblongata. (See Fig.6., Specimen Cat No.III. 9.) This specimen contains four sections taken from different levels extending from the upper limit to about the middle of the Inferior Olive. In all, the left pyramid is filled with degenerated fibres, and a few are seen to pass across the middle line to disappear in the formatio reticularis of the opposite side, while some pass directly backwards and are lost in that of the same side. These fibres cannot be traced far into the reticular formation. Some large pigmented cells are present in the hypoglossal nuclei on each side, but this pigmentation, which is not uncommon in the motor cells of the cat, is quite distinct from degeneration. If this be examined with the high power, no mistake will be made.

Transverse Section Medulla Oblongata. (See Figs 7 & 8, Specimen Cat No.III. 10.) This specimen contains four sections taken from the closed part of the medulla oblongata at different levels.

To face p.86.

CAT No.III.

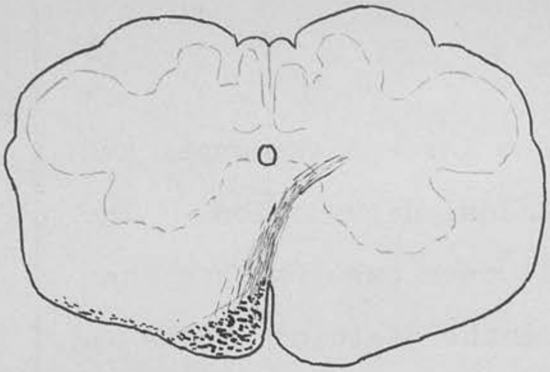

Fig. 7.

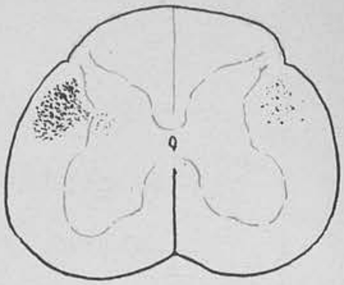

Fig.11.

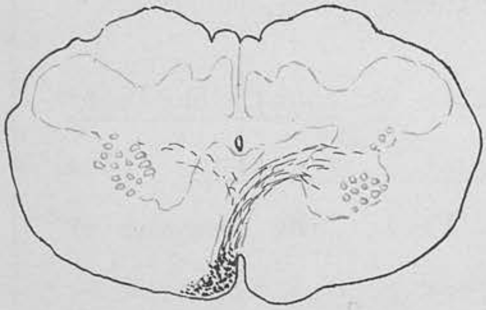

Fig. 8.

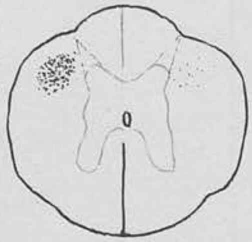

Fig.12.

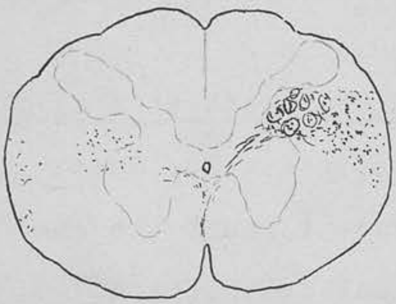

Fig.10.

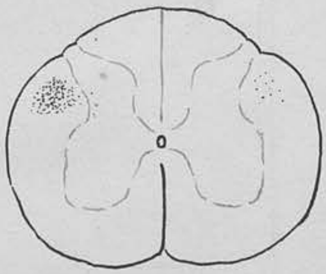

Fig.13.

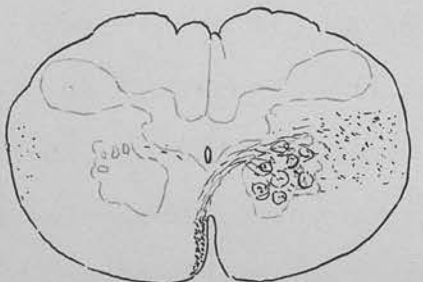

Fig. 9.

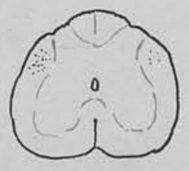

Fig.14.

The two lowest sections pass through the upper and middle regions of the pyramidal decussation. The homolateral fibres are well seen passing from the degenerated pyramid towards the position of the lateral column or crossed pyramidal tract of the same side. A few degenerated fibres are scattered along the margin of the lateral column.

Transverse Section Medulla Oblongata through the Lower Part of the Pyramidal Decussation. (See Fig. 9, Specimen Cat No.III. 11.) The remnant of the degenerated pyramid is seen bordering the anterior median fissure on the left side, and from this the main mass of fibres cross to the other side, while a few pass to the same side.

Transverse Section Medulla Oblongata at a slightly Lower Level than Specimen.II(See Fig.10, Specimen Cat No.III. 12.) This passes through the extreme lower limit of the pyramidal decussation. Many homolateral fibres can be made out in this section passing to the same (left) side. It will be seen on comparing sections taken at different levels throughout the decussation that the bundles of decussated fibres which, in the higher levels lay in the grey matter at the base of the substantia Gelatinosa of Rolando, gradually pass lateralwards as they reach the posterior part of the lateral column in the upper cervical segments of the spinal cord.

(Specimens Cat No.III. 13, 14, 15, 16., Figs.11, 12, 13, 14) show sections of the spinal cord passing through 6th cervical, 8th dorsal, 3rd lumbar and 4th sacral segments respectively. They are practically similar in every respect to those described in Cats Nos I and II. At the level of the 4th sacral segment a few degenerated fibres can be made out in the right crossed pyramidal tract, but none in the left (homolateral).

Cat No. IV

Physical Examination

Animal – Cat No. IV 17th day after operation Weight – 2·96 Kilos

	Right Arm	Left Arm	Right Leg	Left Leg		
Motor						
Voluntary power	?	present	?	present		
~~Grasping~~ "						
~~Hanging on~~ "						
Walking "	Cannot	detect any	defect – no dragging	or stiffness of limbs on right side.		
~~Climbing~~ "						
Sensory –						
Reaction to touch	present	present	?	present		
" " prick	"	"	present	"		
" " clip	"	"	"	"		
" " cold water	at once	at once	at once	at once	Water temp. uncomfortably hot	
" " hot "	" "	" "	" "	" "		
Reflex. Knee-jerk	Most marked on		right side.		Rectum	Room
Temperature	Axilla 100·1 / Ant. fos. 99·3	Axilla 100·2 / Ant. fos. 99·6	Groin 100·5 / Pop. sp. 99·1	Groin 100·0 / Pop. sp. 99·3	100·5° F	75·5° F
State of Vision	Right hemiopia – no mistake about this.					

General Remarks. –

Cat No. IV

Physical Examination

Animal – Cat No. IV   9th day after operation   Weight – 2·63 Kilos

	Right Arm	Left Arm	Right Leg	Left Leg		
Motor						
Voluntary power ---	absent	present	absent	present		
~~Grasping~~ " ----						
~~Hanging on~~ " -----						
Walking " -----	Easily falls over to right side when pushed					
~~Climbing~~ " -----						
Sensory –						
Reaction to touch ---	present	present	?	present		
" " prick ---	"	"	present	"		
" " clip ----	absent	"	absent	"		
" " cold water –	present	"	present	"	Water temp.	
" " hot " ---	slight delay.	at once	at once	at once		
Reflex. Knee-jerk ----	Most marked on right side				Rectum	Room
Temperature ------	Axilla 100·1, Ant. fos. 99·3	Axilla 100·2, Ant. fos. 99·4	Groin 100·0, Pop. Sp. 99·5	Groin 100·3, Pop. Sp. 99·1	100·3	76·5°
State of Vision -----	Right hemiopia – as when last examined.					

General Remarks. –

Cat No. IV

Weight on day before operation 2·86 Kilos

Physical Examination

Animal – Cat No. IV 1st day after operation, Weight – 2·81 Kilos

	Right Arm	Left Arm	Right Leg	Left Leg	
Motor					
Voluntary power ---	absent	present	absent	present	
~~Grasping~~ " ----					
~~Hanging on~~ " -----					
Walking " -----	Lies in cage and will not stand or walk				
~~Climbing~~ " -----					
Sensory					
Reaction to touch ---	absent	present	absent	present	
" " prick ---	"	"	present	"	
" " clip ----	"	"	absent	"	
" " cold water –	"	"	"	"	
" " hot " ---	long delay	at once	long delay	at once	Water temp. uncomfortable for hand
Reflex. Knee-jerk ----	Cannot be elicited on right side				Rectum / Room
Temperature ------	Axilla 99·1 / Ant. fos. 98·2	Axilla 100·4 / Ant. fos. 99·3	Groin 99·2 / Pop. Sp. 98·1	Groin 100·4 / Pop. Sp. 99·6	100·5 / 78·5°
State of Vision -----	Right hemiopia – this was carefully tested				
General Remarks.–					

CAT No.IV.

LESION. This does not extend quite so far back as in most of the other cases. At the post mortem examination the dura mater was found to be adherent over the left sigmoid gyrus, but scarcely at all behind this. The coarse lesion could not be observed in the corona radiata at the level of the head of the caudate nucleus.

SYMPTOMS. There was the usual right-sided motor paralysis, and there was no reaction to any of the tests of sensation, except hot water. From the first, there was right hemiopia, and this continued until the animal was killed. The sensory paralysis was to a large extent recovered from, as also right-sided lameness in walking, but not true voluntary power. The temperature on the right side remained about 1° lower than that on the left for two or three days after the operation.

SECONDARY DEGENERATION.

Transverse Section Midbrain close to Subthalamic Region. (See Fig.1, Specimen Cat No.IV. 1.) The crusta on the left side is degenerated throughout, except its most lateral portion (about $\frac{1}{8}$ of the whole area) which is free from degenerated fibres. From the outer part of the degenerated area a few fibres

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CAT No.IV.

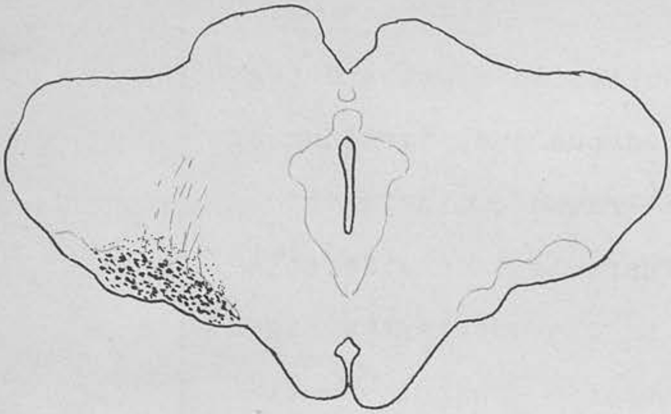

Fig. 1.

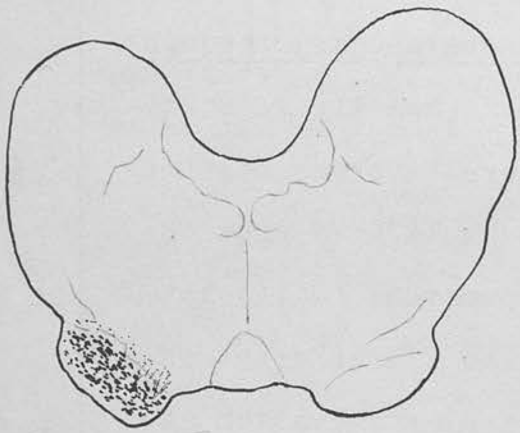

Fig. 2.

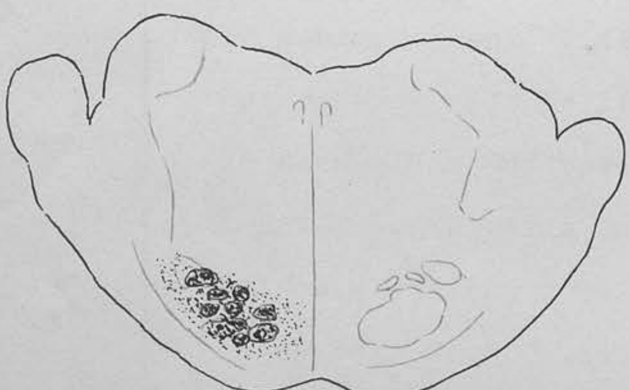

Fig. 3.

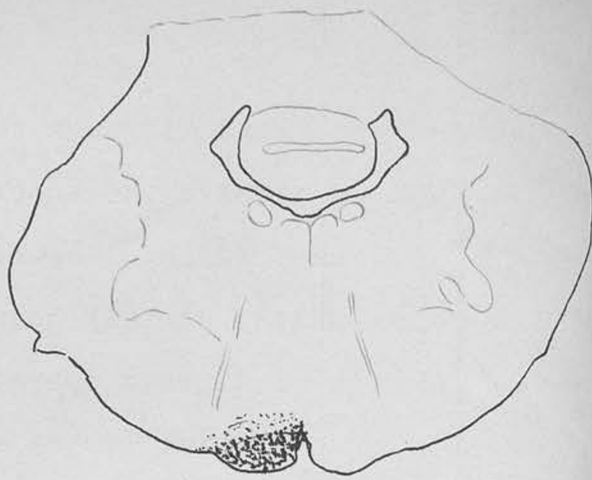

Fig. 4.

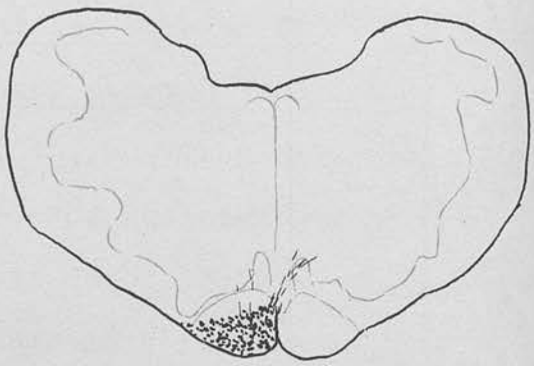

Fig. 5.

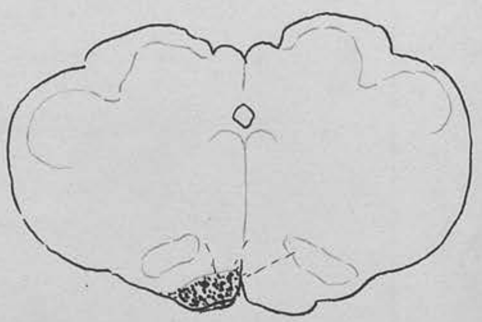

Fig. 6.

run backwards through the substantia nigra and tegmentum towards the anterior corpus quadrigeminum of the same side, but cannot be traced quite to the grey matter of that body. There is a considerable amount of fine degeneration in the substantia nigra lying posterior to the degenerated crusta. No fibres are seen passing to the central grey matter around the Aqueduct of Sylvius, and no fine degeneration is visible in it.

Transverse Section Upper Pons passing through Posterior Corpora Quadrigemina. (See Fig.2, Specimen Cat No.IV. 2.) The left crusta shows scattered degeneration throughout its whole area, but the degenerated fibres are not so numerous at its lateral extremity as elsewhere. No fibres are seen passing backwards into the reticular formation at this level.

Transverse Section through Middle of Pons. (See Fig.3, Specimen Cat No.IV. 3). The pyramidal bundles on the left side are filled with degenerated fibres uniformly scattered over the whole area of their transverse section, and a few degenerated fibres are seen in the trapezium immediately behind the pyramidal bundles. There is much fine degeneration throughout the region of the nuclei pontis surrounding the pyramidal bundles: this is most abundant laterally and does not extend across the middle line. No fibres are seen passing backwards in this region, and there is no trace of degeneration in the grey matter of the floor of the 4th ventricle.

Transverse Section Lower Pons. (See Fig. 4, Specimen Cat No.IV. 4.) This section passes through the root bundles of the 6th and 7th nerves. The left pyramid is degenerated in its whole extent, and scattered amongst the transverse fibres running behind the pyramids are seen numerous black granules. No fibres are visible passing backwards from the pyramids or crossing the raphe.

Transverse Section Medulla Oblongata through Upper Part of Olive. (See Fig. 5. Specimen Cat No.IV 5.) The left pyramid shows extensive degeneration as in the last section, and from it at this level a few fibres are seen crossing the middle line at the bottom of the anterior median fissure and passing into the reticular formation of the opposite side. One or two fibres pass backwards into the reticular formation of the same side.

Transverse Section Medulla Oblongata through Lower Part of Olive. (See Fig.6. Specimen Cat No.IV.6) This presents the same appearance as the last section.

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CAT No.IV.

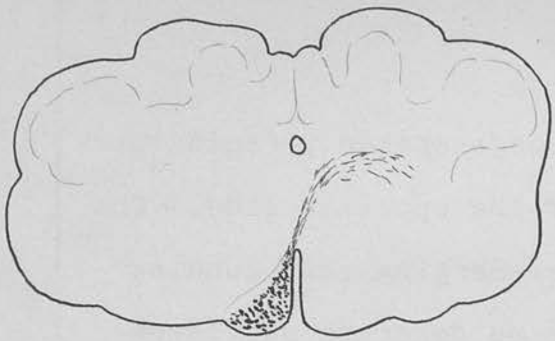

Fig. 7.

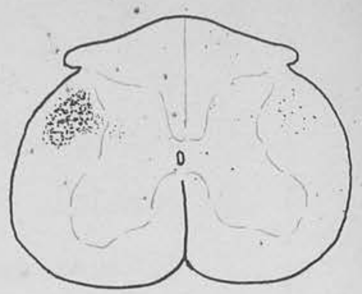

Fig.11.

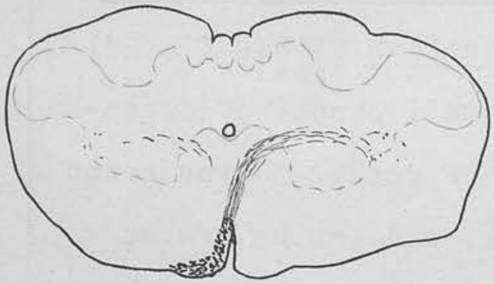

Fig. 8.

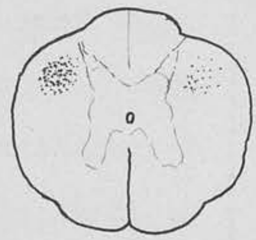

Fig.12.

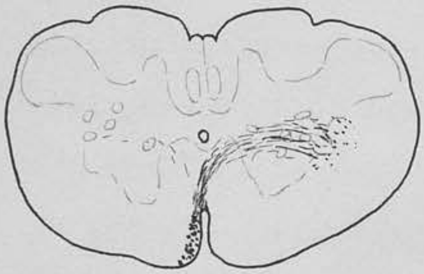

Fig. 9.

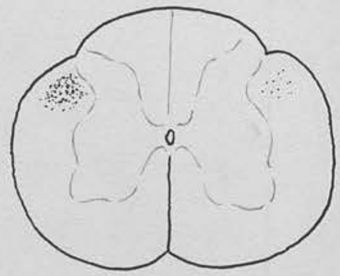

Fig.13.

Fig.10.

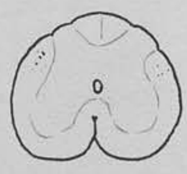

Fig.14.

A few fibres pass from the degenerated pyramid into the formatio reticularis of the opposite side. The hypoglossal nuclei with the emerging root bundles are shown on each side, but no degenerated fibres can be made out passing towards the nuclei.

<u>Transverse Section Medulla Oblongata through Upper Part of Pyramidal Decussation</u>. (See Fig. 7. Specimen Cat No.IV. 7.) A small bundle of degenerated fibres passes across the raphe, curves round in front of the central canal, and can be traced through the grey matter to a point opposite the base of the nucleus cuneatus. No homolateral fibres are evident at this level.

The next three specimens show sections passing through the pyramidal decussation at different levels from above downwards. The crossed and homolateral fibres are well shown, especially in the section passing through the lower part of the decussation. (See Figs 8, 9, 10 and Specimens Cat No.IV, 8. 9. 10.)

<u>Transverse Section Spinal Cord - 6th Cervical Segment</u>. (Fig.11, Specimen Cat No.IV. 11.) The crossed pyramidal tract on the right side is seen as a rounded area containing numerous degenerated fibres in the posterior part of the lateral column.

From it a few fibres pass in towards the base of the posterior horn, and in the grey matter in this position there is a considerable amount of fine degeneration. A few homolateral fibres are visible in the crossed pyramidal tract of the opposite (left) side.

Transverse Section Spinal Cord - 8th Dorsal Segment. (See Fig.12. Specimen Cat No.IV. 12.) This shows right crossed pyramidal tract much reduced in size, and a few homolateral fibres on the opposite side.

Transverse Section Spinal Cord - 3rd Lumbar Segment. (See Fig.13. Specimen Cat No.IV. 13.) The degenerated crossed pyramidal tract is much reduced in size, and contains fewer fibres than in the dorsal region. Only 4 or 5 homolateral fibres can be made out on the left side.

Transverse Section Spinal Cord - 4th Sacral Segment. (See Fig.14. Specimen Cat No.IV. 14.) Only about 10 degenerated fibres can be counted in the right lateral column, and none at all in the left (homolateral).

Cat No. V

Physical Examination

Animal – Cat No. V 17th day after operation Weight – 2.23 Kilos

	Right Arm	Left Arm	Right Leg	Left Leg		
Motor						
Voluntary power ---	Absent	present	absent	present		
~~Grasping~~ " ----						
~~Hanging on~~ " -----						
Walking " -----	Right leg is stiff		and cannot be easily flexed.			
~~Climbing~~ " -----						
Sensory						
Reaction to touch ---	present	present	present	present		
" " prick ---	"	"	"	"		
" " clip ---	"	"	"	"		
" " cold water -	at once	at once	at once	at once	Water temp.	
" " hot " ---	" "	" "	" "	" "		
Reflex. Knee-jerk ---	not examined				Rectum	Room
Temperature ------	Axilla / Ant. fos.	Axilla / Ant. fos. — not taken	Groin / Pop. Sp.	Groin / Pop. Sp.		
State of Vision -----	no hemiopia.					

General Remarks. –

Cat No. V

Physical Examination

Animal – Cat No. V   8th day after operation   Weight – 2.16 Kilos

	Right Arm	Left Arm	Right Leg	Left Leg.		
Motor						
Voluntary power ---	absent	present	absent	present		
~~Grasping~~ " ----						
~~Hanging on~~ " -----						
Walking " -----	Beyond slight stiffness of right leg no defect is noticeable					
~~Climbing~~ " -----						
Sensory						
Reaction to touch ---	present	present	?	present		
" " prick ---	"	"	present	"		
" " clip ----	absent	"	?	"		
" " cold water -	at once	at once	at once	at once	Water temp. uncomfortably hot	
" " hot " ---	" "	" "	" "	" "		
Reflex. Knee-jerk ----	Most easily elicited on right side				Rectum	Room
Temperature ------	Axilla / Ant. fos.	Axilla / Ant. fos. not taken	Groin / Pop. Sp.	Groin / Pop. Sp.		
State of Vision -----	Right hemiopia has passed off – this was carefully tested for					

General Remarks. –

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Cat No. V

Weight before Operation 2·03 Kilos

Physical Examination

Animal – Cat No. V — 2nd day after operation — Weight – 2·01 Kilos

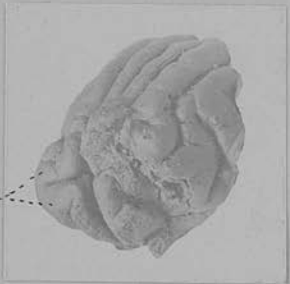
	Right Arm	Left Arm	Right Leg	Left Leg		
Motor						
Voluntary power	absent	present	absent	present		
~~Grasping~~ "						
~~Hanging on~~ "						
Walking "	Drags the right hind leg and has difficulty in flexing it					
~~Climbing~~ "						
Sensory						
Reaction to touch	present	present	present	present	– Responds to the slightest touch applied to either right limb	
" " prick	"	"	"	"		
" " clip	absent	"	?	"		
" " cold water	at once	at once	at once	at once	Water temp.	
" " hot "	" "	" "	" "	" "		
Reflex. Knee-Jerk	Present on both sides but most marked on right					
	Axilla / Ant. fos.	Axilla / Ant. fos.	Groin / Pop. Sp.	Groin / Pop. Sp.	Rectum	Room
Temperature	Not taken					
State of Vision	Right hemiopia.					

General Remarks. – ~~The~~ Sensibility is not diminished on the right side in this case except as regards the "clip test". The animal is not full grown; it is very tame and easily tested so that it is not probable that any mistake has been made.

To face p 93. (middle of page)

1

Right Sigmoid Gyrus



2

Lesion

3

Head of Caudate Nucleus

Ant. horn of Lat. Vent.

This shows only the anterior portion of the hemispheres

Looked at more from the left side than the former cases

CAT No.V.

LESION. After death, the anterior part of the left hemisphere was sliced away, and it was found that the gross lesion had extended backwards into the corona radiata a little way behind the plane of the head of the caudate nucleus, but the optic thalamus was not involved. The animal was killed 23 days after the operation.

SYMPTOMS. There was the usual right-sided motor paralysis, but sensation on that side was unimpaired. The animal responded to tactile, pain, and heat and cold impressions, but it did not react to the "clip-test" when applied to the right foreleg. There was right-sided hemiopia at first, but this passed off within a week after the operation. The knee-jerk was most evident on the right side.

SECONDARY DEGENERATION. There was extensive degeneration of the left motor tract. A few fibres from the left crusta could be traced through the tegmentum to the anterior corpus quadrigeminum of the same side. There was a considerable amount of fine degeneration in the substantia nigra, and amongst the cells of the nuclei pontis. Sections of the spinal cord showed the usual bilateral degeneration down to the sacral region.

Cat No. VI

Physical Examination

Animal – Cat No. VI   12th day after operation   Weight – 3.21 Kilos

	Right Arm	Left Arm	Right Leg	Left Leg.		
Motor						
Voluntary power	?	present	?	present		
~~Grasping~~ "						
~~Hanging on~~ "						
Walking "	Walks	quite well:	takes no	notice when	dorsum of right forepaw is placed on the ground but it will not allow this to be done with the left forepaw.	
~~Climbing~~ "						
Sensory						
Reaction to touch	present	present	?	present		
" " prick	"	"	present	"		
" " clip	absent	"	absent	"		
" " cold water	"	"	"	"	Water temp.	
" " hot "	long delay.	"	long delay.	"		
Reflex. Knee-jerk	Most marked on right side				Rectum	Room
Temperature	Axilla / Ant. fos.	Axilla / Ant. fos.	Groin / Pop. Sp.	Groin / Pop. Sp.		
	not taken					
State of Vision	No hemiopia –		Blind in right eye.			

General Remarks. –

Cat No. VI

Weight before Operation 3·21 Kilos

Physical Examination

Animal – Cat No. VI   1st day after operation   Weight – 3·11 Kilos.

	Right Arm	Left Arm	Right Leg	Left Leg		
Motor						
Voluntary power	absent	present	?	present		
~~Grasping~~ "						
~~Hanging on~~ "						
Walking "	Staggers about the room always falling to the right side					
~~Climbing~~ "						
Sensory						
Reaction to touch	absent	present	present	present		
" " prick	present	"	"	"		
" " clip	absent	"	absent	"		
" " cold water	"	"	"	"	Water temp. too hot for hand	
" " hot "	very long delay	"	long delay	"		
Reflex. Knee-jerk	Can be elicited on both sides but most readily on right				Rectum	Room
Temperature	Axilla / Ant. fos.	Axilla / Ant. fos. — not taken	Groin / Pop. Sp.	Groin / Pop. Sp.		
State of Vision	No hemiopia.		Appears not to see with the right eye but may have been blind in this before the operⁿ			

General Remarks. – This examination was made too soon after the operation.

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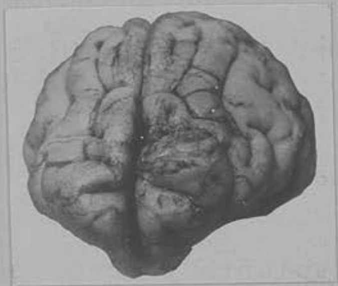
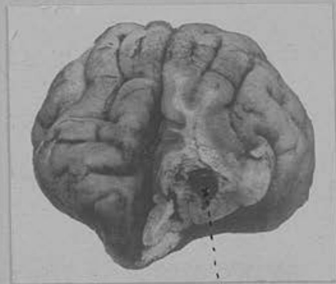
1



2



Lesion.

(These dark or brownish-red areas in the white matter found on slicing away the cortex do not represent the actual lesions made but are due probably to ~~the~~ blood extravasation as the result of these lesions).

CAT No.VI.

LESION. This was made in the usual way, and at the post mortem examination the dura mater was found to be adherent over the anterior part of the left hemisphere. The photograph shows no evidence of any injury to the external motor cortex on the right side, but the mesial cortex may have been damaged, because on examining sections of the brain degeneration could be made out in the internal capsule and crusta on both sides down to the level of the anterior corpora quadrigemina. The animal was killed 15 days after the operation.

SYMPTOMS. There was voluntary motor paralysis in the right fore-limb, but about the hind-limb there was some doubt. Sensation was diminished on the right side. The right eye was blind (which it might have been before the operation, as it was not examined), but there was no defect of vision in the left.

SECONDARY DEGENERATION.

Coronal Section through Middle of 3rd Ventricle (See Fig.1, Specimen Cat No.VI. 1.) The bundles of the left internal capsule contain numerous degenerated fibres, except at the superior (posterior in man) extremity which is free from degeneration. A

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CAT No. VI.

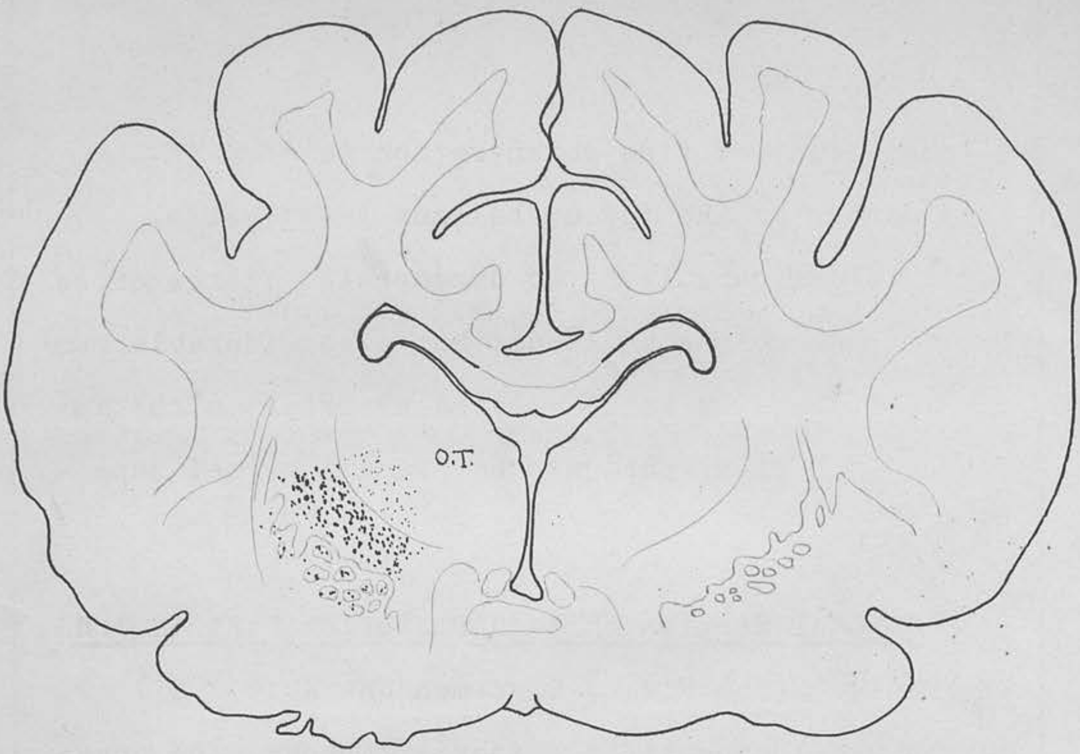

Fig. 1.

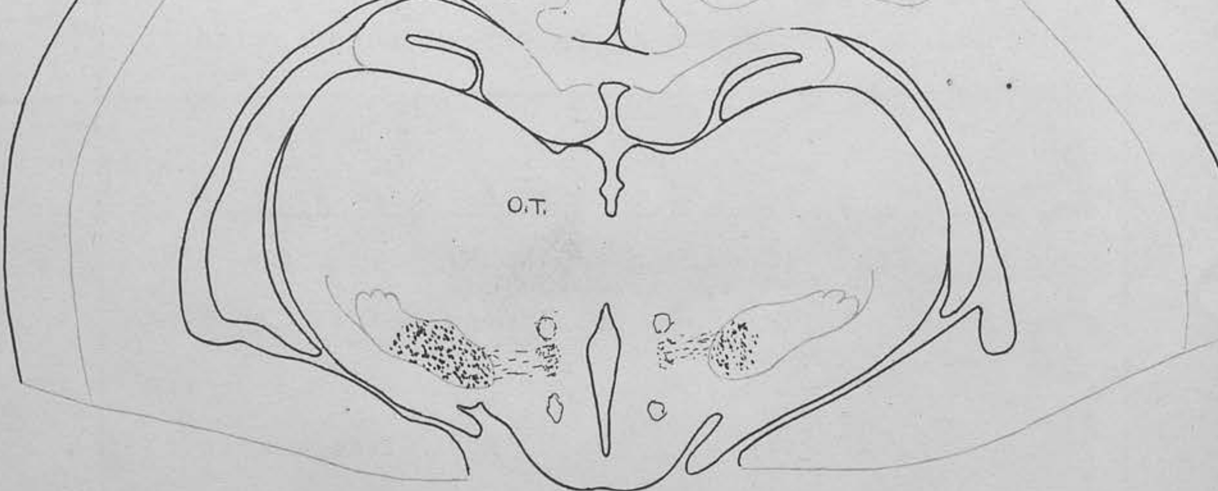

Fig. 2.

slight amount of fine degeneration is seen in the grey matter of the optic thalamus just mesial to the internal capsule. No degenerated fibres cross through the corpus callosum, but a considerable number is visible in bundles lying external to the inferior (anterior) part of the right internal capsule.

Coronal Section through Posterior Part of 3rd Ventricle. (See Fig.2, Specimen Cat No.VI. 2.) The internal capsule (now about to become the crusta) on the left side shows marked degeneration: from its anterior portion many fibres can be seen streaming into the grey matter of the subthalamic region and corpus albicans of the same side. Similar fibres are given off from the anterior or mesial portion of the right capsule to end in a corresponding manner on that side. (The clear area in the right internal capsule is due to imperfect penetration of the osmic acid).

Transverse Section through Anterior Part of Mesencephalon. (Specimen Cat No.VI. 3.) The left crusta shows marked degeneration except in its lateral extremity, and there is abundant fine degeneration in the substantia nigra. About the middle of the right crusta a considerable number of degenerated

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fibres are seen to run directly into the substantia nigra, in which they end in a mass of fine degeneration.

In sections taken slightly below this, the degenerated fibres in the right crusta have disappeared, and at lower levels the degeneration is unilateral. In this animal no fibres were seen to pass backwards from the degenerated crusta to the anterior corpus quadrigeminum. There was much fine degeneration amongst the cells of the nuclei pontis as in all the other cases examined.

CAT No.VII.

LESION. This was practically the same as in the former cases - complete left motor cortical lesion. The animal was killed 23 days after operation.

SYMPTOMS. In this and the three succeeding cases which come early in the series, the symptoms were not tabulated on charts, but short notes of them were taken. On the 2nd day after the operation this animal showed complete motor and sensory (tactile) paralysis on

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the right side, although it appeared to be hypersensitive on the left. It was not tested with hot or cold water. On the 9th day it did not react to a light touch on either right limb, although it showed signs of pain when pricked with a needle. It was found to have right hemiopia - this was not examined before. On the 23rd day the sensory paralysis had disappeared but the hemiopia still persisted. On examining the brain after the animal was killed, it was found that the lesion did not involve the optic thalamus.

SECONDARY DEGENERATION.

There was extensive degeneration of the left pyramidal tract throughout the brain and cord as in the cases already described.

CAT No. VIII.

LESION. Complete left motor lesion.

SYMPTOMS. The animal was not examined till 4 days after the operation. It was found to have voluntary paralysis in both right limbs, and on attempting to walk it fell towards the right side. There was no evidence of any sensory paralysis and

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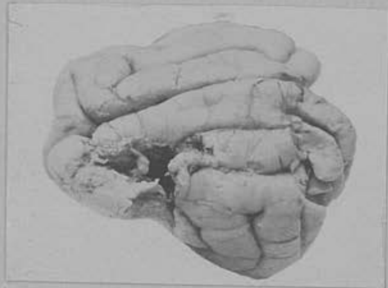

no hemiopia. It was killed at the end of 14 days.

SECONDARY DEGENERATION.

The degeneration of the pyramidal tract in the brain and cord was extensive, involving the whole of the crusta, with the exception of a narrow area along its antero-lateral border. A few degenerated fibres were seen passing backwards from the crusta towards the anterior corpus quadrigeminum of the same side. There was a considerable amount of fine degeneration amongst the cells of the nuclei pontis on the left side.

CAT No.IX.

LESION. This did not extend so near the supero-mesial border of the hemisphere as in most of the other cases: the anterior extremity of the 1st convolution had escaped injury.

SYMPTOMS. On the day following the operation the right fore-limb showed voluntary motor paralysis, but not the hind limb. The animal could walk, but the right fore paw was often bent up underneath it, and it appeared to be quite indifferent to this position of the paw. There was slight sensory

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(Only the anterior portion of the hemispheres is shown in this photo.)

paralysis on the right side - most marked in the fore-limb but present also in the hind. Its reaction to hot and cold water was not tested. There was no hemiopia. At the end of a week the sensory paralysis had disappeared, but the right fore-paw remained rather stiff and was moved awkwardly.

SECONDARY DEGENERATION.

The whole left crusta showed degeneration except the extreme lateral portion. Only one or two fibres were seen passing to the anterior corpus quadrigeminum from the crusta, and there was only a slight amount of fine degeneration in the nuclei pontis. Very little degeneration could be traced below the level of the mid-dorsal region - the hind-limb fibres had escaped.

CAT No.X.

LESION. In this case the incision into the left hemisphere had been made slightly more posterior than in the former cases, and involved a greater part of the cortex anteriorly. On making a post-mortem examination, it was found to extend into the head of the caudate nucleus on the left side.

SYMPTOMS. On the 3rd day after the operation there was voluntary paralysis on the right side, and tactile sensation was absent in the right fore-limb but not in the hind ~~left~~. There was no reaction to cold water in either right limb. Both right limbs seemed slightly swollen and felt hotter to the hand than the left limbs, but the temperature was not taken. There was no hemiopia. On the 7th day after the operation the animal felt the slightest touch on the right side, and withdrew all four limbs from cold water. It was killed at the end of 16 days.

THE SECONDARY DEGENERATION involved the crusta and other parts of the pyramidal tract to the same extent as in the other cases. A few fibres were seen passing from the degenerated crusta through the tegmentum to the anterior corpus quadrigeminum of the same side.

Cat No. XI

Physical Examination

Animal – Cat No. XI   19th day after operation   Weight – not taken

	Right Arm	Left Arm	Right Leg	Left Leg.		
Motor						
Voluntary power	?	present	?	present		
~~Grasping~~ "						
~~Hanging on~~ "						
Walking "	Seems to walk and run about the room as if nothing were the matter with it.					
~~Climbing~~ "						
Sensory						
Reaction to touch	present	present	present	present		
" " prick	"	"	"	"		
" " clip	"	"	"	"		
" " cold water	at once	at once	at once	at once	Water temp.	
" " hot "	delay of 1"	" "	delay of 2"	" "	57°F.	
Reflex. Knee-jerk	Slight kneejerk on right side – none on left				Rectum	Room
	Axilla / Ant. fos.	Axilla / Ant. fos.	Groin / Pop. Sp.	Groin / Pop. Sp.		
Temperature	not taken					
State of Vision	no hemiopia					

General Remarks. – It is extremely difficult to be certain as to whether a cat has voluntary power in a limb or not. Although it does not react to the ordinary tests yet when the stimulus is very powerful it seems to have the power of moving its right limbs voluntarily. When left forepaw and head was held it put out its right paw to catch a ~~piece~~ piece of meat held to it.

Cat No. XI

Physical Examination

Animal – Cat No. XI 9th day after operation **Weight** – not taken

	Right Arm	Left Arm	Right Leg	Left Leg	
Motor					
Voluntary power	?	present	?	present	
~~Grasping~~ "					
~~Hanging on~~ "					
Walking "	No defect is noticeable but when it jumps from the table on to the floor it always falls towards the right side.				
~~Climbing~~ "					
Sensory					
Reaction to touch	?	present	absent	present	
" " prick	present	"	"	"	
" " clip	absent	"	"	"	
" " cold water	at once	"	"	"	Water temp. 57° F.
" " hot "	delay of 3"	at once	delay of 8"	at once	
Reflex. Knee-jerk	Cannot be got on either side				Rectum / Room
Temperature	Axilla / Ant. fos.	Axilla / Ant. fos. — not taken	Groin / Pop. Sp.	Groin / Pop. Sp.	
State of Vision	No hemiopia.				

General Remarks. – In future the temperature of the hot water will be taken and the delay measured by a second's pendulum. Every animal so far has reacted to hot water but sometimes the sensation is delayed for a very long time.

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Cat No. XI

Physical Examination

Animal – Cat No. XI 2nd day after operation Weight – not taken

	Right Arm	Left Arm	Right Leg	Left Leg		
Motor						
Voluntary power ---	absent	present	absent	present		
~~Grasping~~ " ----						
~~Hanging on~~ " -----						
Walking " -----	Walks round in a circle towards the right side: right foreleg is easily doubled under it.					
~~Climbing~~ " -----						
Sensory						
Reaction to touch ---	absent	present	absent	present		
" " prick ---	absent	"	"	"		
" " clip ----	"	"	present	"		
" " cold water-	"	"	absent	"	Water temp.	
" " hot " ---	delay	at once	long delay	at once		
Reflex. Knee-jerk ----	Absent on both sides				Rectum	Room
Temperature ------	Axilla / Ant. fos. – not taken	Axilla / Ant. fos.	Groin / Pop. Sp.	Groin / Pop. Sp.		
State of Vision -----	No defect of vision					

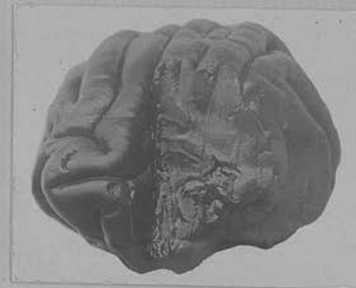
General Remarks. – On the day after the above observations were made the animal was observed to "dress its face" with its right forepaw: This seems to be a purely voluntary act.

To face top of p 101

Cat XI

1

2



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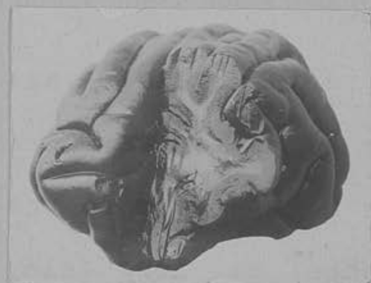

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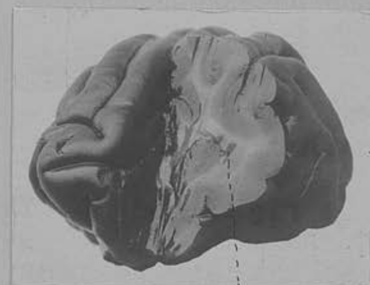

Posterior extremity of Lesion

(Left front view)

Three successive slices have been removed from left hemisphere.

CAT No.XI.

LESION. Calls for no remark: it was made in the same way and involved the same area as in the former cases. This animal was killed 19 days after the operation.

SYMPTOMS. There was voluntary paralysis of both right limbs. Tactile sensation was absent on the right side. There was no response to the cold water test and reaction to heat was long delayed. As time went on, it became difficult to say whether voluntary power was present on the right side or not and tactile, pain and temperature sense returned. The knee-jerk was difficult to elicit, but was most marked on the right side.

SECONDARY DEGENERATION. The crusta, pyramidal bundles and anterior pyramid on the left side showed extensive degeneration. A considerable number of fibres passed from the degenerated crusta to the anterior corpus quadrigeminum, in the grey matter of which there was much fine degeneration. No fibres could be made out going to the central grey matter around the Sylvian Aqueduct. A slight amount of fine degeneration was seen in the pons around the pyramidal bundles, but not so much as in many former cases.

Cat No. XII

Physical Examination

Animal – Cat No. XII 20th day after operation Weight – 2.22 Kilos

	Right Arm	Left Arm	Right Leg	Left Leg	
Motor					
Voluntary power ...	?	present	?	present	
~~Grasping~~ " ...					
~~Hanging on~~ " ...					
Walking " ...	Right leg stiff but no other defect detectable				
~~Climbing~~ " ...					
Sensory					
Reaction to touch ...	present	present	present	present	
" " prick ...	"	"	"	"	
" " clip ...	"	"	"	"	
" " cold water –	at once	at once	at once	at once	Water temp.
" " hot " ...	delay of 1"	" "	" "	" "	57°F
Reflex. Knee-jerk ...	Difficult to obtain on both sides.				Rectum / Room
Temperature ...	Axilla 99.9 / Ant. fos. 99.1	Axilla 100.0 / Ant. fos. 99.3	Groin 99.8 / Pop. sp. 98.9	Groin 100.1 / Pop. sp. 98.9	99.8°F / 75°F
State of Vision ...	as before				

General Remarks. –

Cat No. XII

Physical Examination

<u>Animal</u> – Cat XII 10^d <u>day after operation</u>. <u>Weight</u> – 2.13 Kilos

	Right Arm	Left Arm	Right Leg	Left Leg.	
<u>Motor</u>					
Voluntary power ---	absent	present	?	present	
~~Grasping~~ " ----					
~~Hanging on~~ " -----					
Walking " -----	Right leg is held rigid: when jumps on to floor it falls over towards right shoulder				
~~Climbing~~ " -----					
<u>Sensory</u>					
Reaction to touch ---	present	present	present	present	
" " prick ---	"	"	"	"	
" " clip ----	absent	"	absent	"	
" " cold water -	present	"	present	"	Water temp. 58°F.
" " hot " ---	delay of 1"	at once	at once	at once	
<u>Reflex</u>. Knee-jerk ----	Slight on both sides but more marked on left than right				
<u>Temperature</u> ------	Axilla 100.1 / Ant. fos. 99.3	Axilla 100.4 / Ant. fos. 99.2	Groin 100.1 / Pop. Sp. 99.6	Groin 100 / Pop. Sp. 98.6	Rectum 100.1°F / Room 75°F.
<u>State of Vision</u> -----	no hemiopia.				
<u>General Remarks</u>. –					

To face p. 102.

Cat No XII

Weight two days before operation 2.13 Kilos

Physical Examination

Animal – Cat No XII   3rd day after operation   Weight – 2.11 Kilos

	Right Arm	Left Arm	Right Leg	Left Leg		
Motor						
Voluntary power ---	absent	present	absent	present		
~~Grasping~~ " ----						
~~Hanging on~~ " ----						
Walking " ----	Both right limbs are very weak and the slightest push makes the animal stumble towards the right side.					
~~Climbing~~ " ----						
Sensory						
Reaction to touch ---	present	present	present	present	– appears to be more sensitive on the right side than on the left – responds to the slightest touch on either right limb.	
" " prick ---	"	"	"	"		
" " clip ---	absent	"	"	"		
" " cold water –	absent	"	absent	"	Water temp. 57° F.	
" " hot " ---	delay of 3"	at once	delay of 4"	at once		
Reflex. Knee-jerk ---	absent on both sides				Rectum	Room
Temperature -----	axilla 99.4 / ant. fos. 98.1	axilla 100.2 / ant. fos. 98.9	groin 99.1 / pop. sp. 98.3	groin 100.2 / pop. sp. 99.3	100.5° F.	78° F.
State of Vision ----	no hemiopia.					

General Remarks. – Both right limbs feel hotter to the hand than the left and yet the temperature is about 1° lower on the right than on the left side! The right forepaw is slightly swollen and is certainly hypersensitive: there is no doubt that this limb is paralysed for voluntary movement. Sensory and motor paralysis can have no relation to each other.

Front view (Less than natural size)

CAT No.XII.

LESION. The lesion had not extended far into the corona radiata - not more than half-an-inch. It did not involve the caudate nucleus, although made more posteriorly than in most of the other cases. The animal was killed 20 days after the operation.

SYMPTOMS. At first there was both motor and sensory paralysis on the right side, but the latter was gradually recovered from. In this, as in all the other cases examined, there has always been response to the hot water test, although often after a prolonged period of delay. Water at a temperature which is not comfortable for the hand is not felt for some seconds, and then the animal appears suddenly to feel it very painful. The temperature of the paralysed limbs was about 1° F. lower than that of the opposite limbs.

SECONDARY DEGENERATION. The crusta and pyramids showed degeneration as in the other cases examined. A considerable number of fibres passed backwards to the left anterior corpus quadrigeminum from the degenerated crusta. There was much fine degeneration around the cells of the nuclei pontis on the left side. In the cervical region of the spinal cord a few fibres could be seen passing from the right (degenerated) crossed pyramidal tract into the base of the posterior horn, in which there was also some fine degeneration visible.

Cat No XIII

Physical Examination

Animal – Cat No XIII 19th day after operation. Weight – 2.58 Kilos.

	Right Arm	Left Arm	Right Leg	Left Leg	
Motor					
Voluntary power	?	present	?	present	
~~Grasping~~ "					
~~Hanging on~~ "					
Walking "	no defect				
~~Climbing~~ "					
Sensory					
Reaction to touch	present	present	present	present	
" " prick	"	"	"	"	
" " clip	"	"	"	"	
" " cold water	at once	at once	at once	at once	Water temp. 57° C.
" " hot "	delay 1"	" "	" "	" "	
Reflex. Knee-jerk	Slightly more marked on right than on left side				
Temperature	Axilla / Ant. fos.	Axilla / Ant. fos. not taken	Groin / Pop. Sp.	Groin / Pop. Sp.	Rectum / Room
State of Vision	as before.				

General Remarks. – Exceedingly difficult to make out whether purely voluntary power is absent in right limbs: under strong excitement it appears to be capable of moving both voluntarily.

Cat No XIII

Physical Examination

Animal – Cat No XIII 8th day after operation. Weight – 2·43 Kilos.

	Right Arm	Left Arm	Right Leg	Left Leg	
Motor					
Voluntary power ----	absent	present	absent	present	
~~Grasping~~ " ----					
~~Hanging on~~ " -----					
Walking " -----	Can't detect anything wrong.				
~~Climbing~~ " -----					
Sensory					
Reaction to touch ---	present	present	present	present	
" " prick ---	"	"	"	"	
" " clip ----	absent	"	"	"	
" " cold water	at once	at once	at once	at once	Water temp. 57°C.
" " hot " ---	delay of 1"	" "	delay of 2"	" "	
Reflex. Knee-jerk ----	Exaggerated on right side				Rectum / Room
Temperature ------	Axilla 100·1 / Ant. fos. 99·4	Axilla 100·0 / Ant. fos. 99·2	Groin 99·8 / Pop. sp. 99·1	Groin 100·1 / Pop. sp. 99·8	100·2 / 76°F.
State of Vision -----	as before.				

General Remarks. –

To face p. 103.

Cat No. XIII

Weight before operation 2·56 Kilos

Physical Examination

Animal – Cat No. XIII   2nd day after operation.   Weight – 2·51 Kilos

	Right Arm	Left Arm	Right Leg	Left Leg	
Motor					
Voluntary power ----	absent	present	absent	present	
~~Grasping~~ " ----					
~~Hanging on~~ " -----					
Walking " -----	When pushed easily	falls over to	right side.		Tends to walk in a circle turning always to the right.
~~Climbing~~ " -----					
Sensory					
Reaction to touch ---	present	present	?	present	
" " prick ---	"	"	present	"	
" " clip ----	absent	"	"	"	
" " cold water-	"	at once	at once	at once	Water temp. 57° C.
" " hot " ---	delay of 2"	" "	delay of 4"	" "	
Reflex. Knee-jerk ----	slight on left, absent on right side.				Rectum / Room
Temperature ------	Axilla 100·2 / Ant. fos. 99·5	Axilla 100·0 / Ant. fos. 99·1	Groin 100·3 / Pop. Sp. 99·6	Groin 99·8 / Pop. Sp. 98·9°	100·1° / 77° F
State of Vision -----	no defect of vision.				

General Remarks. – This cat is very wild and difficult to test. The paralysed limbs feel hotter to the hand and the temperature is higher than that of the non-paralysed limbs, – unusual.

To face middle of p 103

CAT No.XIII.

LESION. Same as in former cases.

SYMPTOMS. At first there was right-sided motor paralysis, but no sensory paralysis, except possibly in the right hind limb. There was no response to the "clip-test" on the right fore-limb. The sensation of heat was delayed in both right limbs. The knee-jerk was absent on the right paralysed side, and the temperature was slightly higher on the paralysed than on the non-paralysed side. There was no hemiopia.

SECONDARY DEGENERATION. In this and the three succeeding cases formol had been used as the fixing agent previous to staining with Marchi's fluid, and the fine degeneration is not well seen in any of the sections, but extensive degeneration of the left pyramidal tract could be made out in all.

Cat No. XIV

Physical Examination

Animal – Cat No. XIV   21st day after operation   Weight – 2·02 Kilos

	Right Arm	Left Arm	Right Leg	Left Leg	
Motor					
Voluntary power	absent	present	?	present	
~~Grasping~~ "					
~~Hanging on~~ "					
Walking "	No evidence of any lameness – walks and runs about the room as if nothing were the matter.				
~~Climbing~~ "					
Sensory					
Reaction to touch	present	present	present	present	
" " prick	"	"	"	"	
" " clip	"	"	"	"	
" " cold water	at once	at once	at once	at once	Water temp. 57°C.
" " hot "	no delay	" "	no delay	" "	
Reflex. Knee-jerk	Very difficult to obtain knee jerk on either side.				Rectum / Room
Temperature	Axilla 100·0 / Ant. fos. 99·3	Axilla 99·8 / Ant. fos. 99·2	Groin 99·9 / Pop. Sp. 99·1	Groin 99·6 / Pop. Sp. 99·0	100·1 / 75°F
State of Vision	No defect.				

General Remarks. –

Cat No XIV

Physical Examination

Animal – Cat No XIV   12th day after operation   Weight – 2·01 Kilo.

	Right Arm	Left Arm	Right Leg	Left Leg		
Motor						
Voluntary power	absent	present	?	present		
~~Grasping~~ "						
~~Hanging on~~ "						
Walking "	Can now walk quite well without any apparent lameness but when pushed forwards it falls to the right side.					
~~Climbing~~ "						
Sensory						
Reaction to touch	present	present	present	present		
" " prick	"	"	"	"		
" " clip	absent	"	"	"		
" " cold water	at once	at once	at once	at once	Water temp. 57° ~~3~~C.	
" " hot "	delay of 1"	" "	" "	" "		
Reflex. Knee-jerk	Difficult to get on either side.				Rectum	Room
Temperature	Axilla / Ant. fos. — not taken	Axilla / Ant. fos. — not taken	Groin / Pop. Sp.	Groin / Pop. Sp.		
State of Vision	no defect.					

General Remarks. –

Cat No. XIV

Weight before operation.- 1·91 Kilos

Physical Examination

Animal - Cat No. XIV 2nd day after operation. Weight - 1·89 Kilos

	Right Arm	Left Arm	Right Leg	Left Leg	
Motor					
Voluntary power ---	absent	present	absent	present	
~~Grasping~~ " ----					
~~Hanging on~~ " ----					
Walking " ----	Right hind leg very	weak and flaccid: falls			to right side when attempts to walk.
~~Climbing~~ " ----					
Sensory					
Reaction to touch ---	absent	present	absent	present	
" " prick ---	present	"	present	"	
" " clip ----	absent	"	absent	"	
" " cold water-	at once	"	absent	"	Water temp. 57° ~~F~~ C.
" " hot " ---	delay of 1"	at once	delay of 10"	at once	
Reflex. Knee-jerk ----	very slight on both		sides		Rectum; Room
Temperature ------	Axilla 99·6; Ant. fos. 98·3	Axilla 100·1; Ant. fos. 99·3	Groin 99·7; Pop. Sp. 99·0	Groin 100·1; Pop. Sp. 99·5	100·2; 75·5°
State of Vision -----	No defect		detectable.		

General Remarks.- This animal keeps rotating its head towards the left as it lies in the cage. Has been more disturbed by the operation than is usually the case.

CAT No.XIV.

LESION. Complete left motor cortical lesion. After death the dura mater was found to be adherent over the whole left cortex, but there was no evidence of any sepsis. The animal was allowed to live for 24 days.

SYMPTOMS. There was right-sided voluntary motor paralysis and tactile sensation was absent in both right limbs but as time went on the sensory paralysis was recovered from.

DEGENERATION. As in last case.

Cat No. XV

Physical Examination

Animal – Cat No. XV 20th day after operation. Weight – not taken

	Right Arm	Left Arm	Right Leg	Left Leg		
Motor						
Voluntary power ---	absent	present	absent	present		
~~Grasping~~ " ----						
~~Hanging on~~ " -----						
Walking " -----	No lameness detectable now.					
~~Climbing~~ " -----						
Sensory						
Reaction to touch ---	present	present	present	present		
" " prick ---	"	"	"	"		
" " clip ----	"	"	"	"		
" " cold water -	at once	at once	at once	at once	Water temp. 57°C	
" " hot " ---	" "	" "	" "	" "		
Reflex. Knee-jerk ----	most marked on right side.				Rectum	Room
Temperature ------	Axilla / Ant. fos.	Axilla / Ant. fos. — not taken	Groin / Pop. Sp.	Groin / Pop. Sp.		
State of Vision ----	Hemiopia has passed off: no defect of vision now.					

General Remarks. –

To face p. 105

Cat No. XV

Physical Examination

Animal – Cat No. XV   3rd day after operation.   Weight – not taken

	Right Arm	Left Arm	Right Leg	Left Leg.		
Motor						
Voluntary power	absent	present	absent	present		
~~Grasping~~ "						
~~Hanging on~~ "						
Walking "	When it	attempts to	walk it falls to the right side.			
~~Climbing~~ "						
Sensory						
Reaction to touch	present	present	present	present	– This was very carefully tested.	
" " prick	"	"	"	"		
" " clip	absent	absent	absent	"		
" " cold water	at once	at once	"	at once	Water temp. 57°C.	
" " hot "	no delay	" "	no delay	" "		
Reflex. Knee-jerk	More marked on		left than on right side		Rectum	Room
Temperature	Axilla 99.9 / Ant. fos. 99.1	Axilla 99.3 / Ant. fos. 98.6	Groin 100.0 / Pop. Sp. 99.3	Groin 99.8 / Pop. Sp. 99.1	99.8	78°3
State of Vision	Right hemiopia – carefully examined.					

General Remarks. – This animal recovered very quickly from the shock of the operation. Takes food well and shows no sign of any disturbance except that on walking it often tumbles over to the right side.

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CAT No.XV.

LESION. Left motor cortical as in the other cases. On slicing away the front part of the left hemisphere the lesion was found to extend backwards into the corona radiata not quite to the level of the head of the caudate nucleus. The optic thalamus was not injured.

SYMPTOMS. There was the usual right-sided motor paralysis, but in this case there was no sensory paralysis; right hemiopia was present, however, but this disappeared before the animal was killed.

Cat No XVI

Physical Examination

Animal – Cat No XVI 18th day after operation Weight – 2.58 Kilos

	Right Arm	Left Arm	Right Leg	Left Leg	
Motor					
Voluntary power ----	absent	present	?	present	
~~Grasping~~ " ----					
~~Hanging on~~ " ----					
Walking " ----	Right hind leg is stiff and not easily flexed				
~~Climbing~~ " ----					
Sensory					
Reaction to touch ---	present	present	present	present	
" " prick ---	"	"	"	"	
" " clip ---	"	"	"	"	
" " cold water -	at once	at once	at once	at once	Water temp. 57°C.
" " hot " ---	" "	" "	delay of 2"	" "	
Reflex. Knee-jerk ----	Exaggerated on right side				Rectum / Room
	Axilla / Ant. fos.	Axilla / Ant. fos.	Groin / Pop. Sp.	Groin / Pop. Sp.	
Temperature ------	not taken				
State of Vision ----	as before				

General Remarks. –

Zo face p 106.

Cat No XVI

Weight on day before operation – 2·58 Kilos

Physical Examination

Animal – Cat No XVI 2^d day after operation. Weight – 2·56 Kilos

	Right Arm	Left Arm	Right Leg	Left Leg	
Motor					
Voluntary power	absent	present	absent	present	
~~Grasping~~ "					
~~Hanging on~~ "					
Walking "	will not	attempt	to walk: when placed	on the ground it lies down.	
~~Climbing~~ "					
Sensory					
Reaction to touch	present	present	absent	present	
" " prick	"	"	present	"	
" " clip	absent	"	"	"	
" " cold water	"	"	absent	"	Water temp.
" " hot "	delay of 2"	at once	delay of 12"	at once	57°C
Reflex. Knee-jerk	present on	left side	but not on	right	Rectum / Room
Temperature	Axilla 100·1 / Ant. fos. 99·6	Axilla 100·0 / Ant. fos. 99·4	Groin 99·3 / Pop. Sp. 98·6	Groin 99·8 / Pop. Sp. 99·0	100·2 / 78°F
State of Vision	no defect.				

General Remarks. –

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CAT No. XVI.

LESION. Similar to that described in the former cases. The animal was killed 24 days after the operation.

SYMPTOMS. Right-sided voluntary motor paralysis which seemed to be recovered from in the right leg. Tactile sensation was absent in the right leg as was sensation of cold in both right limbs, and there was a long delay for heat sensation. The sensory paralysis of every kind was recovered from before the animal was killed.

SECONDARY DEGENERATION. Only a few sections have been made of the brain and cord in this case, and these show the usual secondary degeneration of the pyramidal tract. No fine degeneration is visible - due to faulty method employed.

D O G.

As I have already stated, the material from this animal was given me by Professor Schäfer in order that I might examine the secondary degeneration resulting from the lesion which was a deep circumsection of the left sigmoid gyrus.

For a description of the lesion and symptoms following it, I will take the liberty of quoting from a Note read by Professor Schäfer before a Meeting of the Physiological Society on Jan. 26, 1901.

"In the dog experimented on, a cut 5-7 m.m. deep was made well around the sigmoid gyrus. The result of this was to produce paralysis for voluntary motion (inability to hold a bone, awkwardness in walking) and blunted sensibility on the opposite side, and also at first homonymous hemianopsia, which, however, had disappeared by the 5th day. The animal was killed one month after the operation; the circumsected area gave no result on stimulation."

SECONDARY DEGENERATION.

Coronal Section through Posterior Part of Optic Thalamus and Internal Capsule. (Specimen Dog 1.) The bundles of the internal capsule on the left side are markedly degenerated throughout its middle 3/5ths

DOG

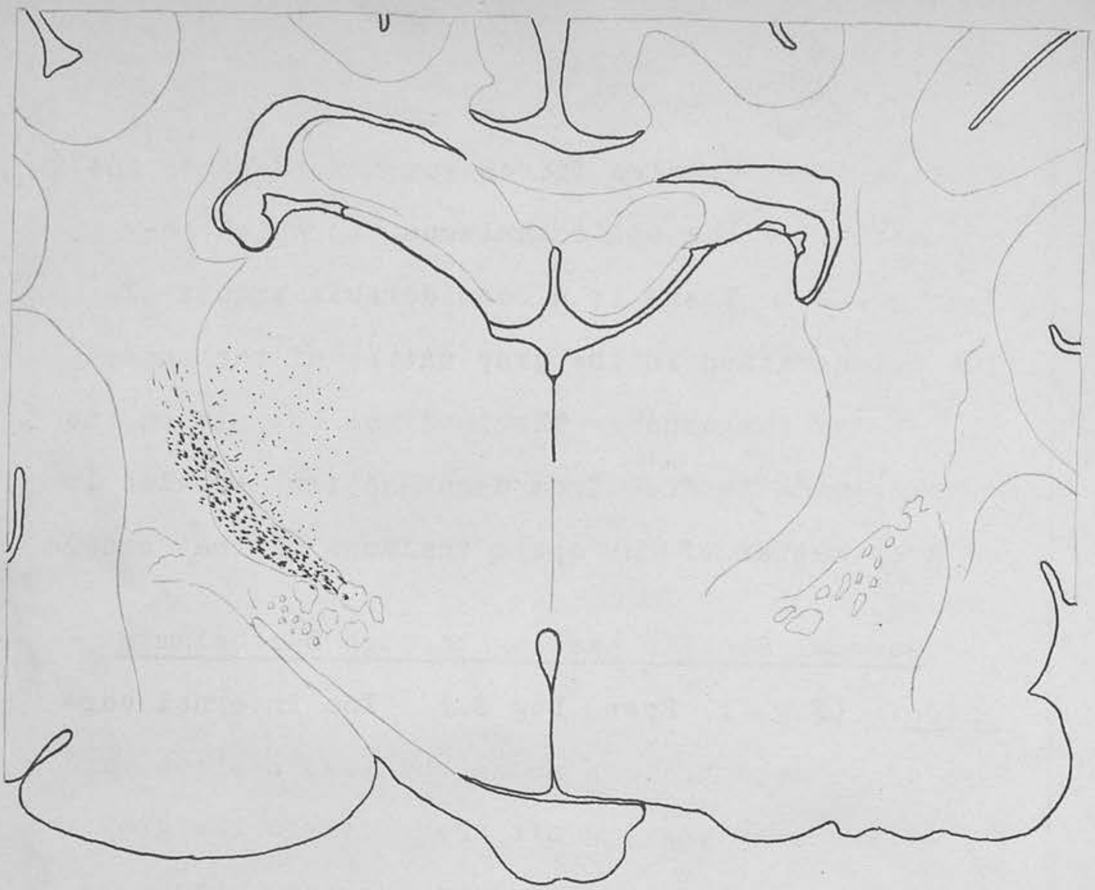

Fig. 1.

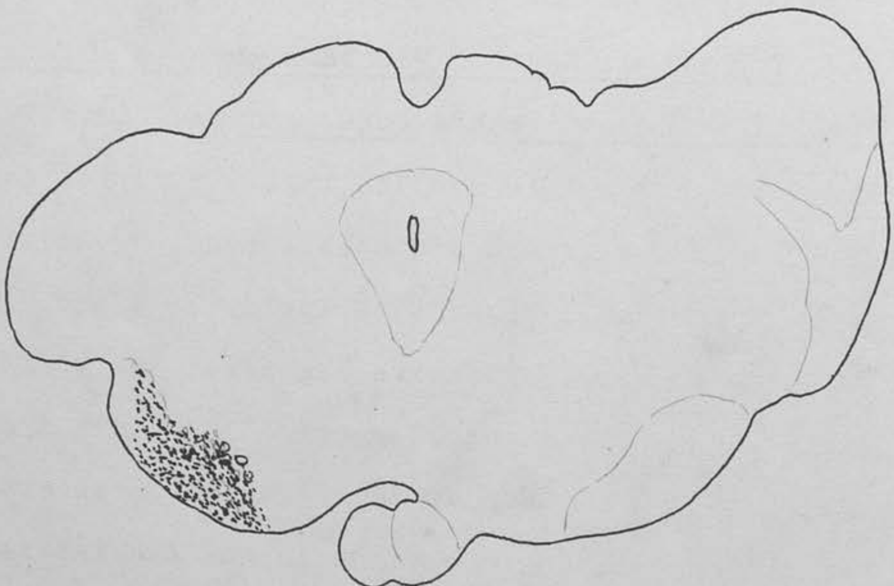

Fig. 2.

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and from these bundles fibres run inwards into the grey matter of the optic thalamus, in which they seem to end. There is a considerable amount of fine degeneration in the grey matter of the outer half of the thalamus. The internal capsule on the opposite side is free from degeneration, as also is the grey matter of the optic thalamus of that side.

Coronal Section passing through Subthalamic Region. (Fig. 1, Spec. Dog 2.) The internal capsule shows degeneration as in the last section, and fibres are seen passing off from it into the grey matter of the optic thalamus on the same side. There are a few black granules scattered amongst the fibres of the optic tract, which lies below and external to the internal capsule.

Transverse Section Midbrain through Anterior Part of Anterior Corpora Quadrigemina. (Fig. 2. Spec. Dog 3.) This section is somewhat oblique and includes the external geniculate body on the right side with a small segment of the optic tract. The left crusta shows extensive degeneration, with the exception of its external margin, and there are many detached bundles of degenerated fibres transversely cut passing downwards in the substantia nigra. There is a very small amount of fine degeneration amongst the grey matter of the substantia

D O G.

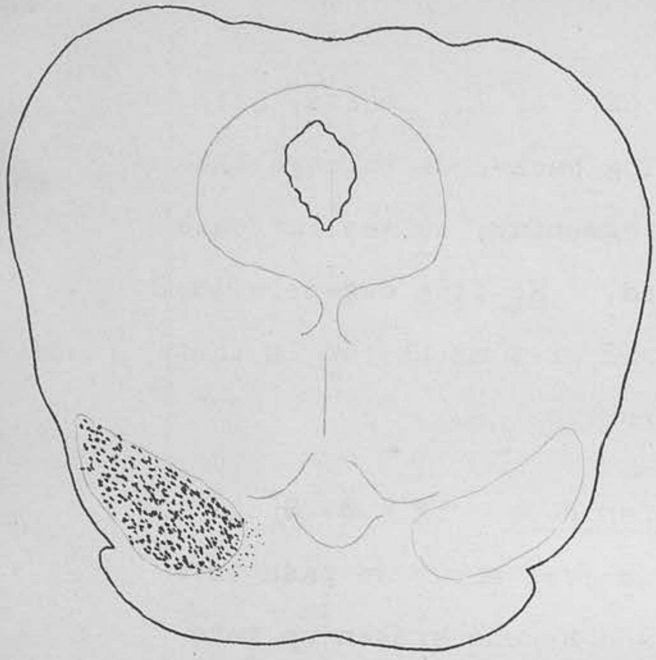

Fig. 3.

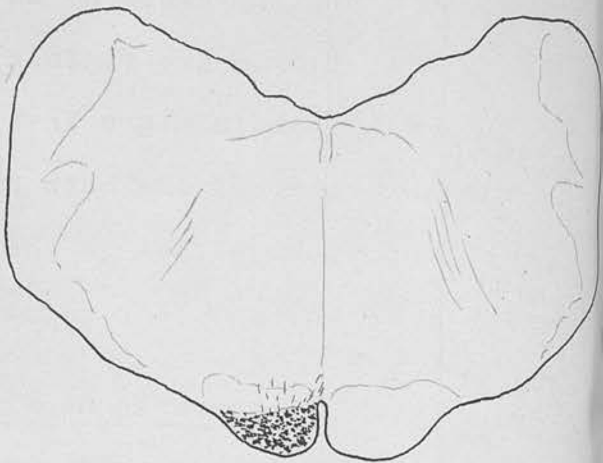

Fig.5.

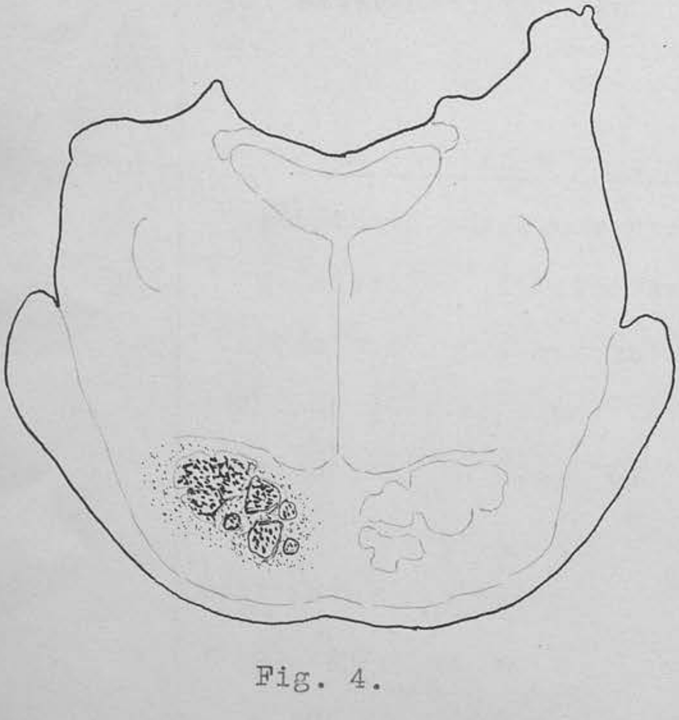

Fig. 4.

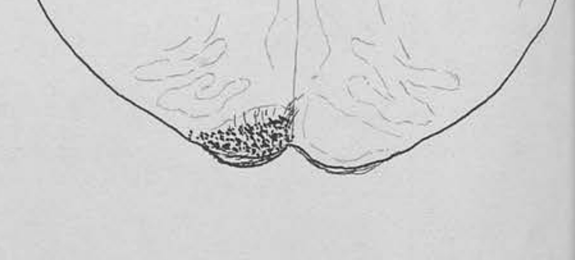

Fig. 6.

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nigra opposite the lateral part of the crusta, but no fibres are visible passing backwards through the substantia nigra into the tegmentum, as was the case in most of the cats examined. No fine degeneration is seen either in the central grey matter or in that of the anterior corpora quadrigemina.

Transverse Section Upper Pons. (Fig.3. Spec. Dog 4.) The left crusta is just about to pass into the substance of the pons and become broken up into the pyramidal bundles: it is degenerated throughout its whole extent; some of the fibres along its anterior margin are cut obliquely. There is a slight amount of fine degeneration opposite the internal extremity of the crusta amongst the transverse fibres of the pons.

Transverse Section through Middle of Pons. (Fig.4. Spec. Dog 5.) This shows the pyramidal bundles on the left side extensively degenerated and all around these, but especially on the mesial and antero-external aspects, there is very abundant fine degeneration amongst the cells of the nuclei pontis. This fine degeneration is exceedingly well marked. No fibres are seen passing backwards from the degenerated bundles and no fine degeneration is visible in the grey matter of the floor of the fourth ventricle.

Transverse Section Medulla Oblongata - Upper Level. (Fig. 5. Spec. Dog 6.) The left pyramid shows uniform and extensive degeneration, and from its posterior aspect many fibres run backwards through the internal arcuate fibres, and, after crossing the median raphe, are lost in the formatio reticularis of the opposite side, while a few end in that of the same side. Three or four black granules are visible in the posterior longitudinal bundle on each side.

Transverse Section Medulla Oblongata through Middle of Olive. (Fig. 6. Spec. Dog 7.) The description given of the last section will apply to this also. In the thick section in this specimen the hypoglossal nucleus and the emerging roots of the nerve are well seen on each side, and a few black granules are deposited amongst the root fibres, but these do not represent degenerated fibres. No fibres from the degenerated pyramid can be traced passing towards or near the hypoglossal nuclei.

Transverse Section Medulla Oblongata - Lower Part. (Fig. 7. Spec. Dog 8.) In this specimen there are several sections taken through the pyramidal decussation at different levels. In each the comparatively large bundle of crossing and crossed

D O G.

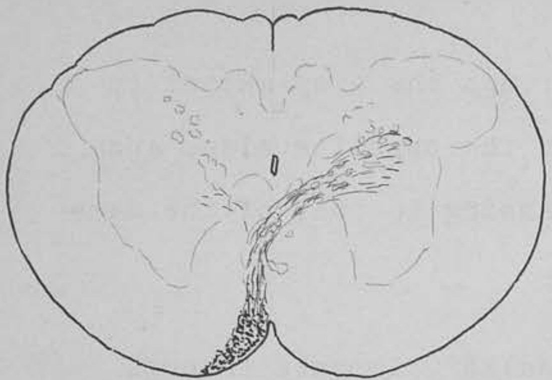

Fig. 7.

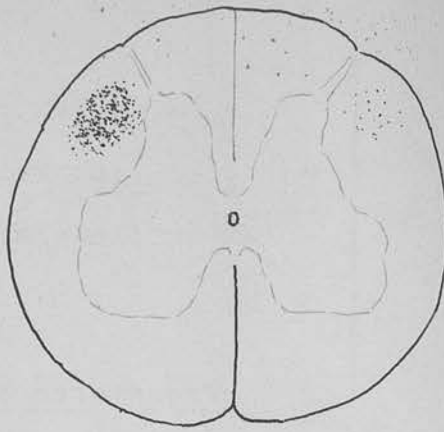

Fig.10.

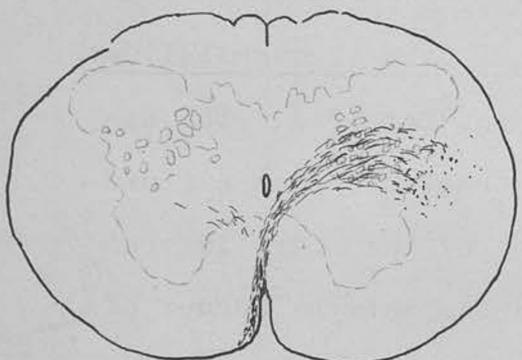

Fig. 8.

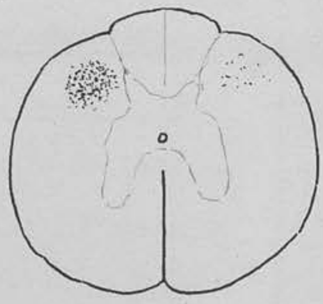

Fig.11.

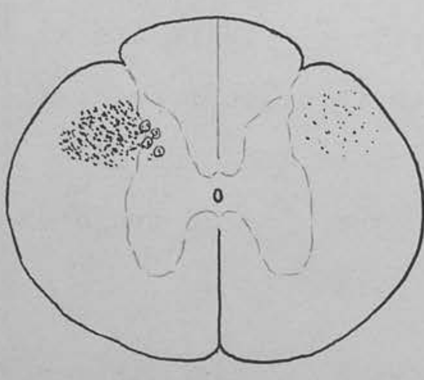

Fig. 9.

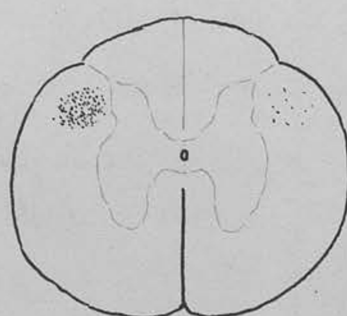

Fig.12.

fibres is seen passing through the grey matter towards the lateral column of the opposite side, and a few homolateral fibres passing to that of the same side.

Transverse Section Medulla Oblongata through the Lowest Part of the Pyramidal Decussation. (Fig.8 Spec. Dog 9.) The crossed and homolateral degenerated fibres are well shown in this, as in the last, specimen.

Transverse Section Spinal Cord through 1st Cervical Segment. (Fig. 9. Spec. Dog 10.) The degenerated crossed pyramidal tract occupies a rounded area in the posterior part of the right lateral column in close contact with the lateral border of the posterior horn. One or two detached bundles are seen within the grey matter at the base of the posterior horn. There is a considerable area free from degeneration between the crossed pyramidal tract and the margin of the section. There are a few degenerated fibres scattered throughout an area on the left side corresponding to that of the degenerated tract on the right. There is no trace of a direct (anterior) pyramidal tract.

Transverse Section Spinal Cord through 6th Cervical Segment. (Fig.10. Spec. Dog. 11.) A rounded patch of degeneration is situated in the posterior part of the right lateral column; it does not reach either the posterior horn or the free margin of the section. No fibres can be made out going towards the base of the posterior horn, and there is no fine degeneration in its grey matter. About a dozen degenerated fibres are seen in the crossed pyramidal tract on the left side.

Transverse Section Spinal Cord - Mid-dorsal Region. (Fig.11. Spec. Dog 12.) The crossed pyramidal tract is seen much reduced in size and containing a comparatively small number of degenerated fibres at this level, but it occupies the same relative position as in the last section. There are a few degenerated fibres in the crossed pyramidal tract of the left side.

Transverse Section - 3rd Lumbar Segment. (Fig. 12. Spec. Dog 13.) The crossed pyramidal tract on the right side , now considerably reduced in size, contains numerous degenerated fibres, and in one or two of the sections in this specimen fibres from this tract are seen to pass into the base of the posterior horn. There are still a few homolateral fibres remaining on the left side.

Monkey No. I

Physical Examination

Animal – Monkey No. I 31st day after operation. **Weight** – 2.71 Kilos.

	Right Arm	Left Arm	Right Leg	Left Leg	
Motor					
Voluntary power ---	absent	present	absent	present	
Grasping " ----	weak	strong	slightly weak	strong	
Hanging on " -----	weak	"	weak	"	
Walking " -----	much improved				
Climbing " -----	climbs better but right limbs still weak and not used much for holding on.				
Sensory					
Reaction to touch ---	present	present	?	present	
" " prick ---	"	"	present	"	
" " clip ----	"	"	"	"	
" " cold water -	at once	at once	delay of 2"	at once	Water temp. 57°C.
" " hot " ---	delay of 3"	" "	delay of 3"	" "	
Reflex. Knee-jerk ----	Most marked on right side.				Rectum / Room
Temperature ------	Axilla / Ant. fos.	Axilla / Ant. fos. not	Groin / Pop. Sp. taken	Groin / Pop. Sp.	
State of Vision -----	as before.				

General Remarks. –

Monkey No. I

Physical Examination

Animal – Monkey No. I 12th day after operation. Weight – 2·75 Kilos.

	Right Arm	Left Arm	Right Leg	Left Leg	
Motor					
Voluntary power ---	absent	present	absent	present	
Grasping " ----	weak	strong	weak	strong	
Hanging on " -----	"	"	"	"	
Walking " -----	Walks better than when last examined				
Climbing " -----	Right limbs are both weak and not used much in holding on				
Sensory					
Reaction to touch ---	present	present	absent	present	
" " prick ---	"	"	present	"	
" " clip ---	"	"	absent	"	
" " cold water -	no notice	at once	absent	at once	Water temp. 57° C.
" " hot " ---	delay of 1"	" "	delay of 5"	" "	
Reflex. Knee-jerk ---	Exaggerated on right side.				
	Axilla / Ant. fos.	Axilla / Ant. fos.	Groin / Pop. Sp.	Groin / Pop. Sp.	Rectum / Room
Temperature ------	not taken				
State of Vision -----	as before				

General Remarks. –

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Monkey No. I

Weight on day before operation 2·81 Kilos

Physical Examination

Animal – Monkey No. I 2nd day after operation Weight – 2·80 Kilos.

	Right Arm	Left Arm	Right Leg	Left Leg		
Motor						
Voluntary power	absent	present	absent	present		
Grasping "	very weak	strong	weak	strong		
Hanging on "	very weak	"	very weak	"		
Walking "	This is	impaired –	not inclined to move	about much		
Climbing "	Can climb	on wire	front of cage	but uses left limbs – holds on very feebly with right.		
Sensory						
Reaction to touch	present	present	absent	present		
" " prick	"	"	present	"		
" " clip	absent	"	absent	"		
" " cold water	"	"	"	"	Water temp. 57°C	
" " hot "	delay of 2"	at once	delay of 6"	at once		
Reflex. Knee-jerk	Exaggerated on		right side		Rectum	Room
Temperature	Axilla / Ant. fos. – not taken	Axilla / Ant. fos. – not taken	Groin / Pop. Sp. – not taken	Groin / Pop. Sp.		
State of Vision	no defect		of vision.			

General Remarks. – This animal was very wild and difficult to test.

To face p ~~##~~ 113.

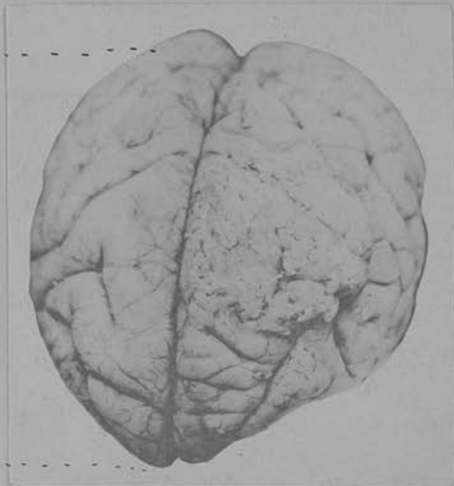

Photo of Brain of Monkey I. Dura adherent over left Rolandic area.

MONKEY No.I (Maca~~que~~cus Rhoesus) - male.

LESION. The motor projection fibres from the left Rolandic area were cut across, as described previously, by making an oblique incision through the grey into the white matter just behind and parallel with the posterior border of the ascending parietal convolution. The incision extended from a point close to the supero-mesial border of the left hemisphere downwards and forwards to a point near the Sylvian fissure. On post-mortem examination the dura mater was found to be adherent over the central portions of the ascending frontal and parietal convolutions. The animal was killed 31 days after the operation.

SYMPTOMS. There was right-sided voluntary motor paralysis and sensory (tactile) paralysis of the right hind limb. To the "clip-test" and cold water there was no response in either right limb, while there was response, but after some delay, to the hot water test. The knee-jerk was exaggerated on the right side. The sensory disturbance passed off to a considerable extent before the animal was killed, and the power of walking and climbing improved, but power of voluntary movement of the right limbs did not return.

MONKEY No.I.

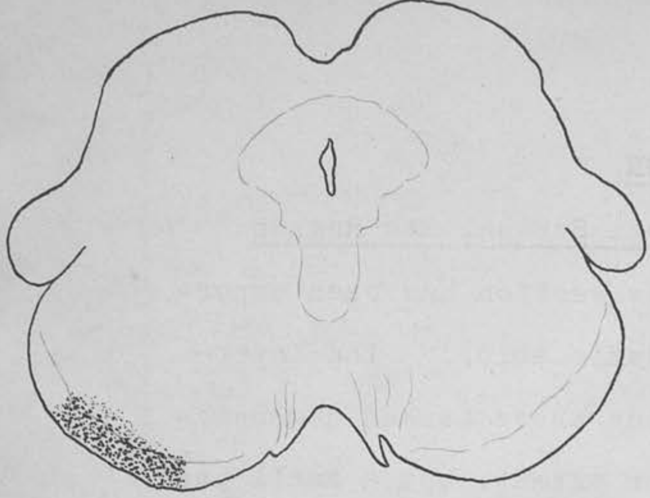

Fig. 1.

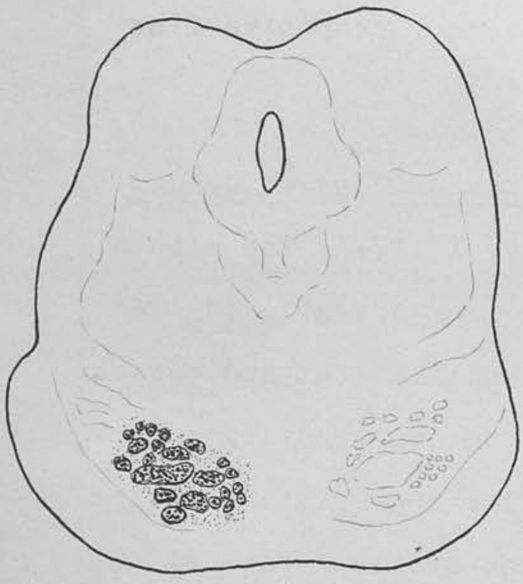

Fig. 2.

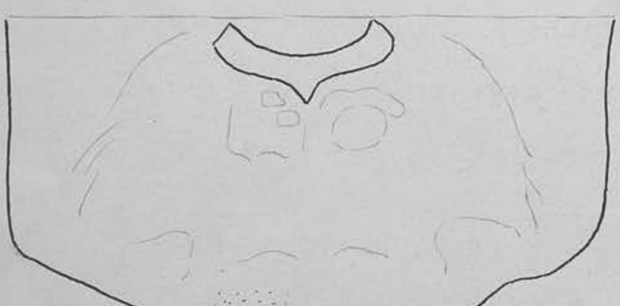

Fig. 3.

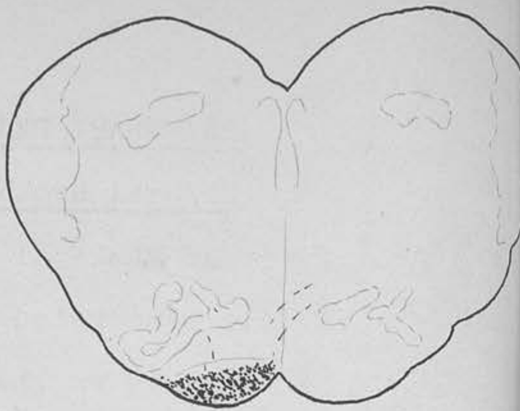

Fig. 4.

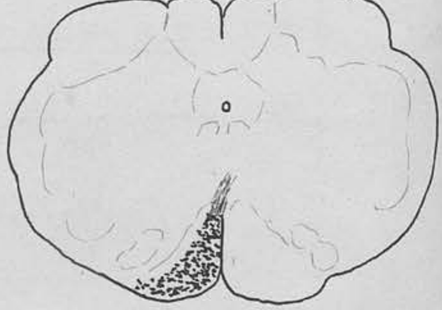

Fig. 5.

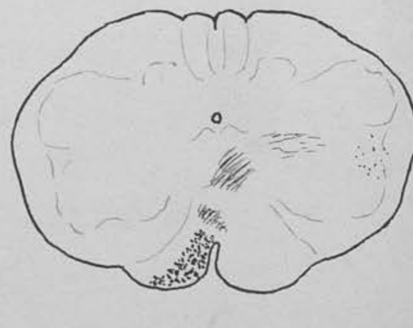

Fig. 6.

SECONDARY DEGENERATION.

Coronal Section through Subthalamic Region. (Specimen Monkey I.1.) (This section has been imperfectly penetrated by the osmic acid). The internal capsule on the left side shows marked degeneration throughout its greater extent, but a small part anteriorly is free from degeneration. Mesial to the capsule in the lateral part of the grey matter of the optic thalamus there is very extensive fine degeneration.

T.S. Midbrain through Anterior Corpora Quadrigemina.. (Fig. 1. Spec. Monkey I. 2.) The crusta contains numerous degenerated fibres scattered over its middle 3/5ths, while its most lateral and mesial 1/5ths are practically free from degeneration. There is a slight amount of fine degeneration in the substantia nigra, but no fibres are seen passing backwards into the tegmentum either towards the anterior corpus quadrigeminum or towards the central grey matter. The cells of the 3rd nucleus are well seen on each side but no fine degeneration is observed scattered amongst them.

T.S. Upper Part of Pons. (Fig. 2. Spec. Monkey I. 3.) The pyramidal bundles on the left side show uniform degeneration, but those lying laterally contain fewer degenerated fibres than the rest. There is a considerable number of degenerated fibres in the lateral portion of the fillet just posterior to the pyramidal bundles. There is very extensive fine degeneration amongst the cells of the nuclei pontis, most marked on the mesial aspect of the degenerated pyramidal tract but not extending across the middle line.

<u>T.S. Lower Pons.</u> (Fig. 3. Spec. Monkey I. 4). The left pyramid contains numerous degenerated fibres, and many small holes can be seen within the area of degeneration - from these transversely cut fibres have fallen out. (This is a formol-hardened preparation). A slight amount of fine degeneration is visible in the region of the nuclei pontis, and amongst the transverse fibres of the pons. Several bands of fine black granules are seen extending backwards and inwards from the degenerated pyramid, but these cannot be traced across the middle line.

<u>T.S. Medulla Oblongata through Middle of Olive.</u> (Fig.4. Spec. Monkey I. 5.) The left pyramid contains numerous degenerated fibres scattered over its whole area, and many vacuoles are visible, similar to those described in the last section and due to the same cause. A few fibres can be seen passing

across the median raphe into the formatio reticularis of the opposite and a few pass backwards to that of the same side.

T.S. Medulla Oblongata through Upper Part of Pyramidal Decussation. (Spec. Monkey I. 6.) A few bundles of degenerated fibres cross the median raphe intermingling with normal fibres from the opposite pyramid: they disappear amongst the internal arcuate fibres on the right side close to the middle line. No homolateral fibres are visible.

T.S. Medulla Oblongata through Middle of Pyramidal Decussation. (Fig.5. Spec. Monkey I. 7.) The left pyramid is much reduced in size at this level and a very large bundle of degenerated fibres is seen crossing the middle line, interlacing with similar bundles from the normal pyramid. Numerous large fasciculi of degenerated fibres, cut transversely, are situated within the grey matter lateral to the central canal: these consist of fibres which have crossed at a higher level and are now descending to reach the crossed pyramidal tract. There are also a few homolateral fibres seen passing towards the crossed pyramidal tract of the same side.

The next two specimens (Fig. 6. Spec. Monkey I. 8 and Fig.7. Spec. Monkey I. 9.) show sections

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MONKEY No. I.

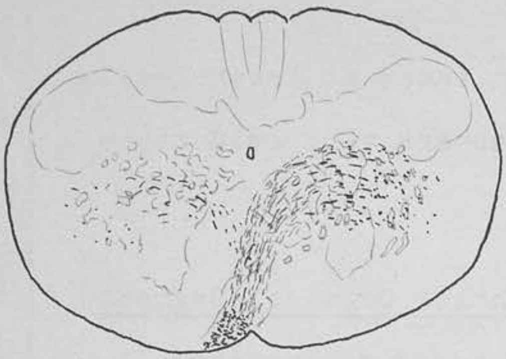

Fig. 7.

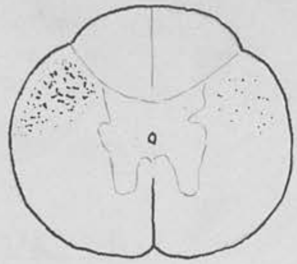

Fig. 10.

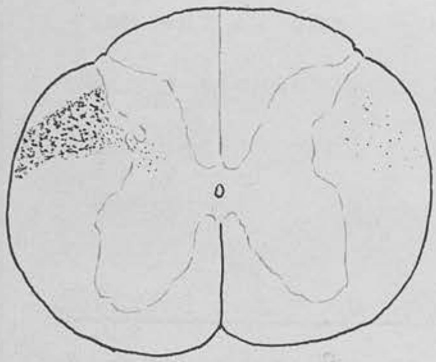

Fig. 8.

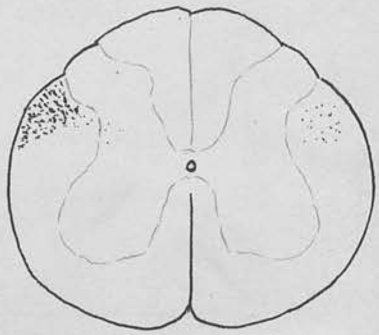

Fig. 11.

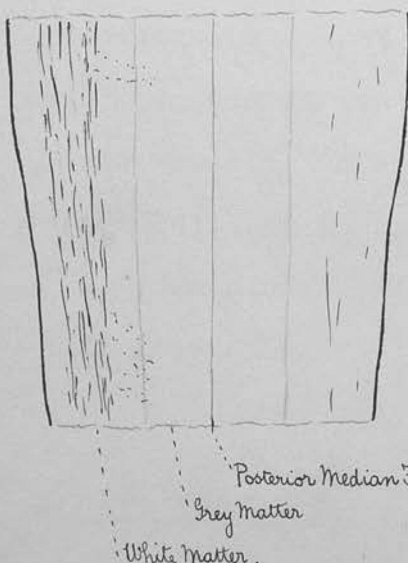

Fig. 9.

Fig. 12.

through the motor decussation taken at lower levels. Crossed and homolateral fibres are very evident in both.

T.S. Spinal Cord through 1st Cervical Segment. (Spec. Monkey I. 10.) Bundles of degenerated fibres, cut transversely, lie amongst the grey matter at the base of the tubercle of Rolando; these are passing down to reach the lateral column at a lower level. Degenerated fibres now extend to the margin of the lateral column. A considerable number of homolateral fibres are present in a corresponding position on the opposite side.

T.S. Spinal Cord through 6th Cervical Segment. (Fig.8. Spec. Monkey I, 11.) The crossed pyramidal tract is seen as a wedge-shaped area filled with degenerated fibres - quite unlike the rounded area in the cat and dog. The direct cerebellar tract is quite free from degeneration. From its inner border a few fibres cut obliquely pass towards the base of the posterior horn, and a considerable amount of fine degeneration can be made out in the grey matter of the posterior horn on that side, while none is visible in any other part. A few homolateral fibres are seen on the opposite side.

Longitudinal Coronal Section through Crossed Pyramidal Tract in Lower Cervical Region. (Fig.9.

Spec. Monkey I. 12.) The tissue has not been perfectly penetrated. The degenerated pyramidal fibres are cut longitudinally, and a few dotted lines indicating collaterals can be seen passing from these into the grey matter of the posterior horn. A few homolateral degenerated fibres cut longitudinally are shown on the opposite side.

T.S. Spinal Cord through 6th Dorsal Segment. (Fig.10. Spec. Monkey I, 13.) The degenerated pyramidal tract is smaller in area, and now reaches almost to the margin of the lateral column: the direct cerebellar tract is very narrow at this level. Homolateral fibres on opposite side are much fewer in number than in the cervical region. No fibres can be seen entering the grey matter.

T.S. Spinal Cord through 3rd Lumbar Segment. (Fig.11. Spec. Monkey I, 14.) A few degenerated fibres can be traced from the degenerated crossed pyramidal tract into the grey matter at the base of the posterior horn, and in this grey matter there is a small amount of fine degeneration. About 10 homolateral fibres are visible on the opposite side.

T.S. Spinal Cord at Level of 4th Sacral Segment. (Fig.12. Spec. Monkey I. 15.) This section shows about 25 crossed and 4 or 5 direct lateral pyramidal fibres degenerated.

MONKEY No.II. (Macaque Rhoesus) - Male.

LESION. The whole of the left motor area was "under-cut", as in the last case, and by a similar operation.

SYMPTOMS. This was the first animal operated on, and the notes kept at the time were very meagre. Following the operation there was conjugate deviation of the head and eyes to the left, which disappeared after the first day. There was right-sided motor and sensory (tactile) paralysis, and right homonymous hemiopia. It was killed 16 days after the operation.

SECONDARY DEGENERATION. In the midbrain, the left crusta in its middle $^3/5$ths was degenerated, the mesial and lateral portions being free, but no fibres could be traced into the tegmentum as in the case of most of the cats examined. There was a considerable amount of fine degeneration in the substantia nigra of the same side. In the pons there was some fine degeneration in the region of the nuclei pontis, but this was masked by a general precipitation all over the section, due to some cause or other in the process of embedding probably. In the medulla oblongata above the level of the decussation proper, a considerable number of fibres leave the degenerated pyramid, and crossing the median raphe, disappear amongst the internal arcuate fibres of the opposite side, while some pass backwards and are lost amongst those of the same side: these fibres cannot be traced far into the formatio reticularis. No degeneration is visible in the grey matter of the floor of the 4th ventricle on either side. (See Specimens Monkey II. 1 & 2.)

Sections of the different regions of the spinal cord showed the usual bilateral pyramidal degeneration, but in these there was a general precipitation throughout due to faulty technique. This was the first material stained by the Marchi method.

SUMMARY of the RESULTS obtained and CONCLUSIONS based thereon.

I. PHYSIOLOGICAL. In the animals used (cats and monkeys), a complete severance of the projection fibres arising from the motor cortex on one side, with as little injury to adjacent parts as was practically possible, was found to be followed by motor paralysis of the opposite side of the body. This was recovered from to a large extent so far as "associated movements" were concerned (power of walking and climbing, &c.), but purely voluntary movements did not return under ordinary circumstances during the time that the animals lived. I say under, ordinary circumstances, because in many cases, in cats at least, when there was a very powerful incentive, apparently voluntary movements were executed with the paralysed limbs, e.g. if, while food was presented to a cat, the animal were prevented from getting at it with its mouth or left paw, it would reach out and catch the food with its right (paralysed) paw. In the cats the "associated movements" were recovered much earlier than in the monkeys.

Regarding the effects of the motor lesion on sensation, there was not the same constancy. Frequently there was deficient or abolished tactile sensibility on the paralysed side, but in many cases this was not so, and in one or two cases there seemed to be hyperaesthesia. As a rule, sensation, when absent or deficient, was early recovered. In no case was there paralysis of the sensation of warmth, although it was often delayed for a surprisingly long time, and after the delay it was usually felt as pain and not warmth, as was indicated by the fact that the animal struggled or uttered cries. In some cases there was homonymous hemiopia, although the post mortem examination showed no injury to the occipital lobe, optic thalamus, or any other part of the optic system. In one cat it lasted as long as the animal lived, but in the others it passed off within a short time.

As a rule, the temperature of the paralysed limbs was lower than that of the opposite side, but in one case it was higher. These differences in temperature between the two sides of the body soon passed off, indicating that the vaso-motor disturbances causing it had disappeared.

The knee-jerk was almost always brisker on the paralysed than on the non-paralysed side.

The point to be emphasised here is, that there is no direct relationship between the motor and sensory paralyses on the affected side of the body, and that, therefore, the motor cortex cannot be the seat of sensation (tactile), as advocated by Munk,[88] Mott[89] and others, but that this must be sought for in some other part of the cortex. The sensory disturbances which often follow cortical motor lesions, are, as pointed out by Schäfer,[87] probably due to the unavoidable injury to other parts of the hemisphere or to altered vascular conditions produced by the operation. When these conditions return to the normal, the sensory paralysis passes off while the motor remains.

<u>II. ANATOMICAL</u>. In the cat, as the result of a lesion cutting off the whole left motor cortex, degeneration was found in the internal capsule of the same side occupying about the middle $^3/5$ths of its whole extent, the anterior and posterior (superior and inferior in the cat) extremities being free. Degenerated fibres were found passing from the centrum ovale through the corpus callosum to the right hemisphere, but none were seen to turn down into the right internal capsule. Opposite the posterior part of the left optic thalamus and in that of the subthalamic region, some fibres leave the capsule, the bundles of which, at this level, are becoming compacted together to form the crusta, and

passing into the grey matter of these regions, end there as fine degeneration. (Fine degeneration is usually interpreted as terminal degeneration - i.e. the degeneration of collateral or terminal fibres). In the upper levels of the midbrain the whole of the left crusta is degenerated, with the exception of a marginal area along its antero-lateral border. From the posterior aspect of the crusta, numerous degenerated fibres pass backwards through the substantia nigra into and through the tegmentum towards the anterior corpus quadrigeminum of the same side. These for the most part end in the grey matter of that corpus, but a few curve round close to its posterior surface and crossing in the roof of the aqueduct are lost in the quadrigeminal body of the opposite side. In only one or two cases were any fibres seen to enter the grey matter around the Sylvian aqueduct, and these did not appear to end there, but to be continued through the lateral portion of it in their course towards the anterior corpus quadrigeminum. In every case throughout the whole extent of the mesencephalon, there was a varying amount of fine degeneration amongst the grey matter of the substantia nigra posterior to the degenerated crusta. In the pons the pyramidal bundles were found to be uniformly degenerated on the side of the lesion, and surrounding these bundles amongst the cells of the nuclei pontis, through which they pass, an extraordinarily large amount of fine or terminal degeneration was observed in the case of every animal examined. No fibres were seen to pass backwards from the pontine pyramidal bundles towards the grey matter of the floor of the 4th ventricle, as had been observed from the crusta in the midbrain, and no fine degeneration was present in that grey matter. In the upper levels of the medulla oblongata, when the pontine bundles have united again to form the anterior pyramid, a few fibres begin to leave the posterior aspect of the degenerated pyramid: most of these cross the median raphe and are lost amongst the internal arcuate fibres of the formatio reticularis of the opposite (right) side, whilst some disappear in that of the same side. Similar fibres continue to pass backwards from the degenerated pyramid throughout its whole extent in the bulb until the upper extremity of the true decussation is reached. They run not towards the grey matter in the floor of the 4th ventricle or around the central canal in the lower or closed part of the bulb, but more lateralwards towards the base of the substantia gelatinosa of Rolando. They cannot be traced far into the reticular formation. No fine degeneration was seen in the grey matter of the floor of the 4th ventricle in any part of the medulla oblongata, and this was carefully looked for, more especially in the region of the hypoglossal nucleus. When the motor decussation proper is reached, bundles of fibres are observed to come off from the postero-internal angle of the degenerated pyramid, and, after crossing the middle line, to pass backwards towards the lateral portion of the grey matter around the central canal, and then to curve more outwards and become lost as they turn canalwards in their passage towards the lateral column (crossed pyramidal tract) of the spinal cord. I have seen no fibres passing in a similar direction from the degenerated pyramid towards the same side (homolateral) until the middle of the decussation is reached, and from this level downwards these homolateral fibres increase in number. Redlich[76] says these homolateral fibres come off in greater abundance from the middle $^2/4$ths of the decussation. When this region of the medulla is cut serially, they are missed in several consecutive sections and then appear again. This is due to the fact that they come off in small bundles comparatively widely separated from each other vertically. The ratio between the decussating and non-decussating fibres varies much in different animals of the same species, and the relative numbers can only be known by

Caudal

counting the fibres on each side in sections through the upper cervical cord, and not by comparing the two sides in any one section through the decussation. Down to the level of the pyramidal decussation a few black dots have been observed in transverse sections of the pyramidal tract of the side opposite to the lesion in several of the earlier animals, but whether these represented degenerated fibres or were accidental, it would be difficult to say. In the case of material which was prepared later in the course of the research, when more experience had been gained, the degeneration was almost invariably wholly unilateral down to the level of the decussation. In the cervical region the crossed pyramidal tract occupies a comparatively small rounded area in the posterior part of the lateral column close to the antero-lateral aspect of the posterior horn, but not reaching the margin of the section. A few fibres are seen to pass in towards the base of the posterior horn, and some fine degeneration is present in this region of the grey matter. A few homolateral or uncrossed degenerated fibres, varying in number in different animals, occupy a corresponding position in the lateral column on the side of the lesion. In the dorsal, lumbar and sacral regions (beyond the 4th sacral segment, no section was examined) fibres representing both direct and crossed lateral pyramidal tracts are present in gradually diminishing numbers.

I had intended to count the degenerated fibres in order to find out in what regions throughout the brain and cord they disappeared in greatest number, but on making the attempt I found that the time at my disposal would not admit of this being done with any degree of accuracy. The transverse section of any part of the pyramidal tract contains fibres of all sizes apparently, - coarse, medium, fine, and as many subdivisions as one chooses to make. I do not believe that what would in transverse section be classed as a medium fibre need necessarily represent a degenerated fibre of medium thickness, and for this reason:- the myelin in the process of degeneration breaks up into globules, and these stained black by the osmic acid may be seen quite distinctly in a longitudinal section of a nerve fibre. A transverse section of such a globule would appear as a coarse medium or fine fibre according as the globule happened to be cut through its centre or nearer one extremity, so that a medium or fine granule in the transverse section of a degenerated tract need not necessarily represent a medium or fine nerve fibre. Where, however, fine degeneration only is visible, fine fibres alone can have been present.

In the dog examined, the above description applies for the most part, but with one notable exception, viz., that no fibres could be observed passing backwards from the degenerated crusta in the midbrain towards the anterior corpus quadrigeminum. There was in the pons the same amount of fine degeneration amongst the cells of the nuclei pontis; indeed this was more marked in the dog than in any of the cats with one exception.

In the monkeys, two in number, the degeneration occupied about the middle $^3/5$ths of the crusta and not its whole area, with the exception of a narrow margin along its antero-lateral border, as it was found to do in the case of the cats and dog. Below the level of the midbrain throughout the whole extent of the pyramidal tract in all the animals examined, the degeneration was scattered practically uniformly over the area of its transverse section, and in every case at every level there were normal fibres mingled with the degenerated ones.

In neither of the two monkeys examined were any fibres found passing from the crusta to the grey matter of the anterior corpora quadrigemina, but there was abundant fine degeneration amongst the

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- Observe the fibre passing from external extremity of degenerated crusta to the lateral portion of the central grey matter around the aqueduct of Sylvius.

Photograph from Plate accompanying Muratoff's Paper.

cells of the nuclei pontis. Again, in the spinal cord the pyramidal tracts both crossed and homolateral were much more extensive in transverse section and contained many more fibres than was the case in the dog and cat.

For the most part the observations above recorded agree with those of former workers using Marchi's method; but there are one or two points to which I would desire to call special attention.

1. With regard to the fibres leaving the crusta and passing backwards to the anterior corpus quadrigeminum in the cat, only one previous observer, viz. Boyce [(71)] in 1894, so far as I know, has found similar fibres. This he did in two cases - both cats - after a unilateral motor cortical lesion. He describes these fibres as coming off from the outer extremity of the degenerated crusta. I have observed them leaving its whole posterior aspect as well as the outer extremity. He states that similar fibres had been figured by Muratoff, [(66)] but in the photograph of Muratoff's drawing appended, it will be seen that the fibres or fibre (for only one is represented) go towards the lateral portion of the central grey matter - apparently to the nucleus of the 3rd nerve. I have found these fibres in 14 out of 16 cats, but I have not been able to find them in

the dog, or in either of the 2 monkeys. Before saying, however, that they do not exist in these animals, a greater number would require to be examined. What particular region of the motor area they come from I have not as yet been able to determine, although I mean to make an attempt to do so at an early date, and what their significance is I am unable to say. It may be that they are indirectly connected through the grey matter of the anterior corpora quadrigemina with the nuclei of the nerves of the eye muscles (nuclei of the 3rd and 4th nerves) situated in this region, i.e. that a short neurone is interpolated between the terminations of these fibres in the anterior corpora quadrigemina and the cells of origin of the fibres of the oculomotor and trochlear nerves. In this connection it would be interesting to determine whether they come from the "head and eyes" area of the motor cortex. Another possibility is, that they may end in relation to the cells of origin of some other tract which starts in the anterior corpora quadrigemina and passes down to a lower level. These are points still to be determined. I have been able to show in the course of my investigations that these fibres are present in the great majority of cases in the cat, at all events, and it would be interesting to know whether

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Degenerated pyramidal bundles. (No fine degeneration is represented)

they are represented in other animals, for it is very improbable that the cat is the only mammal in which they occur.

2. No one has observed, or at any rate, called attention to the exceedingly large amount of fine degeneration which occurs amongst the cells of the nuclei pontis, with the single exception of Dejerine and Long (78) in an article published in 1898. This contains a record of the examination of material from 5 cases of cerebral hemiplegia suitable for the Marchi method. They say, "In the grey substance of the pons the very fine and very numerous granules which we have observed in two of the cases indicate a degeneration of collateral and terminal fibres at this level, and this fact explains to us the atrophy of the grey substance of the pons which one sees in old degenerations of the crus cerebri." In all the animals I have examined, as in the two cases in the human subject recorded by Dejerine and Long, this fine degeneration has been present, and often exceedingly abundant. It is a well-known fact that atrophy of the nuclei pontis followed degeneration of the crusta, and that, therefore, these cells had some connection with the motor tract, but the extent and importance of this connection has possibly been overlooked. Cajal (90) considers that

these terminal fibres or collaterals take part in the formation of a centrifugal cortico-ponto-cerebellar tract, i.e. that they form synapses around the cells of the nuclei pontis which cells give origin to processes or fibres that pass to the lateral lobe of the cerebellum of the opposite side, and there in turn arborise around Purkinje's cells. This may be so, but it is not probable that it would account for all the terminal or collateral fibres which are seen to end throughout the whole extent of the pons from its upper to its lower limit. This terminal degeneration is strictly confined to the side of the pons on which lie the degenerated pyramidal bundles; none appears across the middle line. The cells of the nuclei pontis around which these fibres or collaterals end may be situated directly on the motor path, and represent either a short intercalation between the terminations of the upper motor neurones and the cell bodies of the cranial motor nuclei, which would in that case correspond to the third motor neurone, or a long intercalation between motor fibres terminating in the pons and cells situated in the spinal cord. In either case, it would be necessary to suppose that the processes of these cells cross the middle line; but even then, this arrangement would only be analogous to the crossing of the second neurone on the sensory path, viz., from the cuneate and gracile nuclei to the fillet of the opposite side. All this, however, is mere speculation. What I would desire to call attention to is the fact that such a marked terminal degeneration exists in the pons.

3. I have never been able to trace any degenerated fibres from the main pyramidal tract to or even towards any of the cranial motor nuclei as Mellus,(70) Hoche,(77) Romanow(79) state they have succeeded in doing, nor have I ever seen fine degeneration amongst the cells of these nuclei, or anywhere in the central grey matter. Boyce,(71) Dejerine and Long,(78) and many other observers, expressly state that they also have failed to do this. In several animals I have made serial sections from the upper limit of the mesencephalon to the lower limit of the bulb, and in not one have I found degenerated fibres passing to any of the cranial motor nuclei. To this it may be said, that these nuclei are supplied by collaterals which are not readily revealed by the method of Marchi; but such fibres could be traced with the greatest ease from the crusta right up to the grey matter of the anterior corpus quadrigeminum of the same side, and even across the middle line to that of the other side; and, if they exist, why can they

not be traced to, or at all events near to, the cranial motor nuclei? The reason is possibly, that they do not exist. No fibres at all were seen to pass backwards from the degenerated pyramidal tract (with the exception of the above mentioned) until the upper limit of the medulla oblongata was reached and below this throughout the whole extent of the medulla and not alone opposite any particular nucleus, e.g. the hypoglossal, a few fibres continued to be given off from the degenerated pyramid, most crossing the middle line at once, and disappearing in the formatio reticularis of the opposite side, comparatively few passing backwards and being lost in that of the same side. These are probably the fibres which some observers have supposed go to the motor nuclei of the cranial nerves situated in the bulb and lower pons. They are not directed towards the grey matter in which these nuclei lie, but seem for the short distance to which they can be traced, to pass more lateralwards, and possibly they belong to the spinal motor decussation, being destined for the lateral columns of the cord - crossed and direct. That is to say, the pyramidal decussation is not confined to the lower part of the medulla, but occurs to a limited extent in the upper part as well.

4. I have been able to trace fibres from the

crossed pyramidal tract in the cervical, and to a slight extent in the lumbar, enlargements into the base of the posterior horn, thus corroborating the observations of Professor Schäfer.(92) These fibres were most evident in the monkey, but were also seen in the cat. None could be made out going towards the anterior horn. They are not so abundant when the lesion is a cortical one as when the cord has been hemisected, so that possibly in the latter case they come from more than one source.

There is still great difference of opinion amongst neurologists with regard to the terminations of the pyramidal fibres, both in the spinal cord and in the medulla and pons. Most believe that by means of collaterals and terminal fibres they form synapses directly around the cells of the anterior cornua and of the motor nuclei of the cranial nerves. Monakow holds that, in the spinal cord at least, a second neurone is interposed between the pyramidal fibres and the cells of the anterior horn, its function being to bring a single pyramidal fibre into relation with many anterior cornual cells. The cell-body of this intercalated neurone lies amongst the grey matter in the region of the processus reticularis, while its branching processes arborise round several cells in the anterior horn. The number of fibres in the pyramidal tract at any level of the cord is infinitely smaller than the number in all the anterior nerve roots below that level, each of which takes origin in a motor cell in the anterior horn, and if the pyramidal fibres are directly related to the peripheral motor cells, it must be by means of numerous collaterals given off in their passage down the cord. If such collaterals exist they are seldom seen. The conception of Monakow is the more probable. It might be suggested that the cells of the nuclei pontis represent in the higher levels those which Monakow believes to be situated near the processus reticularis in the spinal cord, and that these intervene between the pyramidal fibres and the cells of the cranial motor nuclei. The question is one to which at the present time it seems difficult to give an answer; but the evidence in favour of Monakow's idea of intercalated neurones between the central and peripheral motor neurones appears to be increasing.

In conclusion, I wish to thank Professor Schäfer for having suggested to me this line of research, and for the many facilities afforded me in his laboratory during its prosecution.

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