PHILOSOPHICAL TRANSACTIONS.

I. *Results of Hemisection of the Spinal Cord in Monkeys.*

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[PLATES 1–4.]

WHILE engaged in studying experimentally the connections of the cells of CLARKE'S column with the ascending tracts of the spinal cord in the Monkey, I was surprised to find that after hemisection in the lower dorsal region, the sensory disturbances produced in no way corresponded with those already obtained by an eminent observer.

I was, therefore, led to continue my experiments, with the aid of a grant from the British Medical Association, and by the kind permission of Professor SCHÄFER I carried them out in the Physiological Laboratory of University College. My thanks are also due to him for much valuable advice and assistance.

The subject is one of great importance from a scientific as well as from a clinical point of view. Some years ago a case occurred in my practice which tended to shake my faith in the absolute truth of the doctrine of complete and immediate decussation of sensory impulses in the spinal cord, as taught by BROWN-SÉQUARD.

The experiments which I have performed exhibit the following principal points of interest:—

1. Return of associated movements after complete destruction of the crossed pyramidal tract below the lesion.

2. That all sensory impulses do not decussate in the cord; in fact, they appear to show that certain sensory impulses, *e.g.*, touch, the muscular sense, and localization in space, pass chiefly up the same side, painful impressions up both sides. A peculiar condition known as "allochiria" occurs after hemisection.

3. The vaso-motor disturbances are on the same side as the lesion, and consist of

vaso-dilatation, swelling of the foot, and redness, with rise of temperature of the skin of the foot, but, as compared with the opposite side, fall of temperature in the popliteal space on the side of the lesion, due, no doubt, to paralysis of the muscles.

4. The degenerations above and below the lesion are limited to the same side, when the injury is perfectly unilateral. There are certain facts connected with the degenerations which serve to show the origin and course of certain long and short tract fibres.

5. Stimulation of the cortex cerebri on both sides some weeks or months after the hemisection had been performed gave, as a rule, *results* which showed that the block in the spinal cord produced by the hemisection still existed, although there had been a very complete return of associated movements.

6. In one case, ablation of the leg area on the same side as the lesion in the spinal cord was performed many months afterwards.

I will now leave this brief introduction to proceed with my subject in detail under the following headings :—

I. Method of Experiment.

II. Notes of Cases, nine in number.

III. Results of Experiments.

1. Motility.
2. Sensibility.
3. Reflexes.
4. Vaso-motor and temperature.
5. Results of cortical stimulation.
6. Extent of the lesions and resulting degenerations.

IV. General Principles deduced from these and other observers' experiments in regard to the conducting tracts of the cord.

V. Brief *résumé* of the literature of the subject.

VI. Hyperæsthesia, its production and cause.

VII. Clinical aspects.

METHOD OF EXPERIMENT.

Rhœsus Monkeys were generally used, but in two instances Bonnets. The animal having been anæsthetized with a mixture of chloroform and ether was placed upon a flat tin vessel containing hot water. Its back was shaved over the portion of the spine upon which it was proposed to operate. A pad was placed underneath so as to make the vertebræ prominent. An incision was made along the middle line and the spines of the vertebræ exposed. The muscles on each side of the spines were then cut through. The periosteum in most cases was stripped off the sides of the spinous processes and from the laminæ. The spines of one or two vertebræ were then removed with bone forceps. By means of an eye speculum the muscles were kept apart, and

the operator was thus enabled to expose the spinal cord contained in its membranes. The dura is then seized with a pair of *very* fine toothed forceps, and is opened by means of a fine blunt-pointed pair of scissors. The posterior median artery will now be seen, and can be gently pulled aside or avoided by passing the cataract knife, used to make the hemisection, a little obliquely under the vessel. As a rule there is very little hæmorrhage. In some cases two, three, or more hemisections were made at a distance apart of 1 to 2 millims., in order to destroy half the cord for a longitudinal extent of $\frac{1}{2}$ centim. or more, and sometimes a blunt probe was put in the gap formed by the section. In one instance a small piece of celloidin was introduced, and in two cases the hemisection by cataract knife was completed with scissors. This was the least satisfactory mode. In nearly every instance the actual hemisection was performed in the presence of Professor SCHÄFER. The wound was closed with horse-hair sutures, and the whole operation was performed with strict antiseptic precautions. A thin layer of antiseptic gauze was placed over the wound and then painted with collodion. *In no instance* did the antiseptics fail; the wounds healed by first intention. Frequently new bone formed, closing in the spinal canal, and, in some cases, the formation of connective tissue union was so perfect that the place of incision could not be discovered after removal of the cord. This was notably so in one instance, when, having shown the spinal cord to an eminent young surgeon and told him that I had made hemisection some months previously, I asked him to point out the seat of the lesion. He was unable to do so. And yet the degeneration showed that a complete hemisection had been made. I relate this because my experience has been to show that some of the symptoms, notably hyperæsthesia on the side of the lesion, are due to the lesion not being strictly localized. In some cases, however, there was a little prominence of cicatricial tissue firmly adherent to new bone formed from the periosteum left behind (*cf.* Case V.). The animals were kept under the anæsthetic for some time after the operation in order that the collodion dressing might set firmly. The temperature of the room was kept between 70° and 80°, and in every instance the animal, though paralyzed, was found sitting up the next day and taking his food well.

I am strongly of opinion that the complete success of the antiseptics and the method of operation described was the cause of such successful results which enabled me to test the animal as to the sensory and other disturbances effected by the operation.

The collodion dressing was usually taken off and the stitches removed at the end of a week. In two or three cases there occurred an accumulation of cerebro-spinal fluid, which had to be let out by puncture. The temporary paraplegia which occurred in two cases was thus relieved.

The results of these experiments are successful enough to encourage more frequent operative measures for spinal disease in Man.

Notes of Cases.

Case I.

Bonnet Monkey ♂.—Hemisection of the cord on the right side, between the 3rd and 4th dorsal nerves. Four hours later temperature of the right popliteal 97°·6, left 98°·4. Paralysis of right leg owing to drowsy condition from anæsthetic not having passed off; the sensory disturbances could not be tested satisfactorily. The *next day* there was complete paralysis of all the muscles of the right leg. Temperature of right popliteal space 98°·2, left 100°·4. Several trials made to be quite sure. With regard to sensation there was diminished sensibility on both sides when tested with a needle. As far as I could judge he would respond as soon to a prick on the right side as on the left; the abdomen, leg, and foot being tested.

3rd day.—Tested the animal with Professor SCHÄFER by pricking with a needle. It was concluded that it felt better on the non-paralyzed side. With the interrupted current stimulation with fine-pointed electrodes led to response on non-paralyzed side when the secondary coil was distant 11 centims. from the primary: on the paralyzed side when distant 9 centims. The plantar surface of the right foot was swollen, red, and hotter to feel than the left.

5th day.—Temperature sense was tested. Piece of metal heated by dipping in hot water placed upon the sole of the foot and other parts of the body, gave rise to a response on both sides. The temperature was daily tested in the popliteal space of the two sides and the rectum. It was found on the non-paralyzed side to correspond within a decimal point or two with that of the rectum. On the right or paralyzed side it was 1° to $1\frac{1}{2}$° lower.

The animal was tested every few days for the next month, and it seemed that tickling sensations, such as scratching with the blunt end of the needle, pricking with the point, or the faradic current, were responded to on both sides.

30th day.—Knee-jerk exaggerated both sides—more marked on the right. The limb seems atrophied, but muscles respond to faradism. The animal can use both limbs, flexion of knee and hip being now fairly strong. Can support himself with his right foot on the bars of the cage, but he does not grasp with that foot. A black cap was put over his head and he walked much more slowly and carefully, but climbed up the wire work of the cage. The temperature of left popliteal space is still a little higher than the right.

32nd day.—Section of left half of the cord between 9th and 10th dorsal nerves. Within two minutes of the section the left foot began to swell and look red. This operation caused complete paraplegia. The next day the following notes were taken. Animal very well, except that he is paralyzed in both legs absolutely. The abdominal muscles were not observed to be paralyzed. He seems to feel a little in the foot on both sides; about the root of the tail he is quite insensitive. When a hot spoon is placed upon his foot he takes no notice of it until some time has elapsed, when, guided by sight, he attempts to remove it. The feet are swollen and dry on both sides. The temperature of the soles of the feet and popliteal space could not be registered, being below 95°; in the axilla of the left side it was 96°·6. Two days later, by means of a surface thermometer, the sole of the left foot registered 95°, while the sole of the right foot registered 92°. This was anticipated, as the left foot was swollen, and felt warmer. On the other hand the left popliteal space registered 97°·2, the right 97°·2, and the axilla 99°·8. It was noticed when I put the thermometer in the popliteal spaces that the animal, which was lying half asleep, looked round. It coughed frequently, and in doing so used its abdominal muscles, though somewhat feebly.

The next day. Temperature, right popliteal space, 97°·2; right axilla, 99°·8; left popliteal space, 97°·2; left axilla, 99°·8; left plantar surface, 95°·2; and right plantar surface, 94°·6.

A week after this operation the animal died of broncho-pneumonia.

The spinal cord was removed and placed in bichromate of potash.

The method adopted for hardening the cord has been the same in all cases, and is as follows:—A glass stopper was attached to the roots of the cauda equina, and the cord which had been removed with the greatest care to avoid bruising was suspended in a tall vessel containing the hardening solution. The vessel with its contents was placed in a warm chamber, by which the hardening process is greatly facilitated. In two days the spinal cord was sufficiently hardened to allow of transverse sections being made, which divide it into a number of small segments held together by the membranes.

In this way the spinal cord can be perfectly hardened in two months, and the method has the advantage of preserving the structures intact, for if transverse cuts into the cord be attempted immediately on removal, damage might easily be effected, especially at the seat of the lesion.

After hardening in the bichromate solution, the cords were placed in spirit, and then portions of about $\frac{1}{4}$ inch in length, including, of course, the lesion, were imbedded in celloidin, and thin sections cut by the freezing microtome, and stained by WEIGERT's or PAL's method. Sections of the spinal cord above, below, and at the seat of the lesions, were made and mounted in oil of cloves and Canada balsam. Photo-micrographs of the sections were also prepared, and these exhibit the extent of the injury and the resulting degenerations.

For the lesion in Case I. see Plate 1.

Case II.

Healthy Rhœsus ♀.—Hemisection made on the left side at the last dorsal segment.

2nd day.—Animal draws up the right leg only. Sensation could not be satisfactorily tested, owing to the animal being very frightened, but it flinched with a sharp prick at the root of the tail on either side. Otherwise took no notice.

3rd day.—The animal feels pricking on the back of the thigh and the root of the tail on both sides about equally; is paralyzed in the left leg, and knee-jerk not obtainable.

7th day.—Left leg completely paralyzed. Diminished sensation to pricking in the right leg. Diminished sensation in the sole of right foot and posterior part of calf.

14th day.—Very difficult to decide if there is any difference in the two sides with pricking or stimulation.

17th day.—I tested the animal with Professor SCHÄFER. He considers there is diminished sensation on paralyzed side. Animal can now use both legs for climbing. Temperature—right popliteal 100°·6, left 98°·6. The sole of the left foot was much hotter than that of the right at first, but later on, when the swelling had gone down and the dryness had disappeared, the temperature of the plantar surface was lower than on the non-paralyzed side.

24th day.—Animal was found dead, and, from the heat of the room, decomposition had already occurred, rendering the cord almost diffluent. To the naked eye the hemisection seemed complete,* but

* It was very difficult to test this animal, owing to its being very wild. The only inference that can

this could not be determined owing to the soft myelin oozing out at the lesion. The cord was hardened in bichromate of ammonia, and sections of the cord just above the lesion prepared (*vide* Plate 1).

Case III.

Healthy Rhœsus ♀. Hemisection on the left side between 5th and 6th dorsal roots. The points of a pair of forceps were introduced into the cut to insure that the separation was complete. Next day, twenty hours after operation, the animal was tested. It was sitting up, quite lively, and had apparently perfectly recovered, with the exception of paralysis of the left limb. I was assisted in testing this animal by Mr. L. E. HILL. There was complete paralysis of the left limb. Immediately after the operation it had been noticed that the left foot was swollen, red, and hotter to feel than the right. This was still apparent, but not so markedly. The unequal action of the abdominal muscles noticed immediately after the operation, was not so apparent. Sensation was tested in the following ways. The animal's head was turned aside, and its attention attracted by Mr. HILL while I touched the plantar surface of the foot with a metal rod previously dipped in hot water. It was noticed that the animal felt on both sides. On the right side (non-paralyzed) it responded to the test, and localized the spot excited, putting the hand of the same side down and scratching the place. On the paralyzed (left) side the animal remained unconscious of the stimulation longer, but when it did respond, seemed to be more agitated. This may be explained by the fact that the longer duration of the stimulus produced greater effect.

When the toes of the right foot were dipped into hot water they were quickly withdrawn; when the toes of the left side were dipped into the same a struggle occurred, but on both sides the response of the stimulus was delayed. Tested by pricking, the animal responded on both sides; the place excited was localized on the non-paralyzed side by the animal scratching the part with its hand. Temperature, left popliteal space, 96·2; right, 98; left plantar surface, 94; right ditto, 87·5.

3rd day.—Sensibility tested by electricity. Animal gave evidence of feeling on both sides. Knee jerks well marked on both sides.

14th day.—During the interval sensation remained on both sides; animal can now localize on the left side. The redness and dryness of the foot is less marked, and movement is returning in the muscles of the hip and knee joints.

24th day.—No loss of sensation anywhere when tested by pricking or heat. The left popliteal space is a degree lower than the right. The skin of the sole of the left foot is *now* moist, and there is no swelling; it is also perceptibly cooler than the right, indicating that the vaso-motor paralysis has passed off. Temperature registered by surface thermometer is six degrees lower than the right.

The animal was placed in a large cage, where it could have free movement.

The return of movement in this animal became daily more pronounced, and *ten weeks* after the operation it was very difficult to tell which side was paralyzed. Following note then made:—Sensation perfect both sides, muscles of left leg not quite so well developed as right, but not flabby, and respond to faradism; movements of hips, knees, and ankle perfect, but it is noticed upon careful observation that the foot drags a little, as if there were delay in the voluntary impulses. Temperature, 102° in each popliteal space. A clip placed on the soles of the feet alternately is removed immediately by the animal.

In later experiments I used *the clip method* of testing sensation, which involves tactile pressure and painful sensations. These sensations being conveyed to the brain, give rise to certain conscious voluntary impulses necessary for the animal to

be drawn is, that the animal felt on both sides. In the later experiments that I have made, I have adopted better methods of testing the sensibility.

remove the clip with its hand. This also shows whether the muscular sense is present or not ; for, unless the animal were conscious of the position of its foot in space, it would be unable to remove the clip. In all the remaining five cases this test was applied, and it was invariably found that the animal removed the clip immediately, or within a few seconds from the non-paralyzed side, which it would not do if it did not feel it, although the test does not show absolutely whether the sensation which directs the Monkey to place its hand down to the foot in order to remove the cause of excitation is tactile, painful, or both. But from the rapidity with which it is effected, and from the facial expression of the animal, it would seem to be a painful one, probably tactile, too. The animal never removes the clip from the paralyzed side until movements have returned on the affected side. Certain precautions were taken to make this test a reliable one. The clip was fixed on the foot when the animal's attention was attracted away, for if it saw what was done, it would remove the clip from the paralyzed side, although, generally speaking, it would not do so until some time had elapsed ; and I was led to believe from this test that it did not feel so well on the paralyzed side as on the healthy side.

To make sure of the validity of this test the animals were anæsthetized with ether, and a clip fixed on each foot; when they came to they invariably removed the clip from the non-paralyzed side, leaving the other hanging on.

Another peculiar fact noticed in connection with this test was that, when the clip was fixed on the paralyzed foot, the animal would draw up the sound one, examine it and scratch it several times, then give it up.

In one case this phenomenon was noticed under the following circumstances. The animal having been anæsthetized, a clip was fixed on the paralyzed foot—when it recovered consciousness it lifted up the non-paralyzed foot, scratched and examined the same part as that to which the clip was fixed on the other foot. This test only answered satisfactorily when applied to the sole of the foot, the animal would take very little notice of it when applied to other parts of the body except the hand.

All physiologists, who have had expereince in testing the sensibility of the skin in Monkeys, are agreed that the animals often behave indifferently to pricking, and other sensory tests. This clip test, which was introduced by SCHIFF, is undoubtedly more satisfactory than any other, because we have evidence that the stimulus excites a conscious, purposive act, indicating volitional impulses from the brain, whereas pricking, hot water, and other tests may simply give rise to simple spinal reflex movements.

The explanation of these phenomena will be attempted later.

42nd day.—Sensibility, as tested by pricking, hot water, and clip, apparently the same on the two sides. The left leg is wasted, but movements good. On close inspection the animal is seen to drag the foot a little in walking. The temperature in the popliteal spaces is almost the same—only a difference of 0°·2 F. being now observed, the right registering 102°, the left 101°·8. The surface of the right foot registered 100° F., left 97°.

74th day.—Sensibility to the usual tests perfect on both sides. Muscles of left leg not quite so well developed as those of the right, but not flabby. Movements all performed, but left foot is dragged a little, as if there were some delay in voluntary movements.

77th day.—The animal was anæsthetized, and the following experiment was performed, in which I had the valuable assistance of Professor SCHÄFER, as also in others of a similar nature, for it is impossible for one person to carry out such experiments single-handed.

The cortex cerebri of the motor area was exposed, and the following notes were made :—faradisation with a moderately strong current of the leg area *on the left side*, caused well-marked movements of the ordinary character in the right leg, followed by epilepsy.

Stimulation of the leg area *on the right side*, caused, in the first place, movements in the right hallux; secondly, in left ham strings; thirdly, general drawing up of left leg, accompanied to some extent by movements of right leg. More ether was then given, and strong stimulation of the right leg area produced no effect on the left leg, *but* movements in the limb of the same side.

The same stimulation of the left side caused very strong movements of the right limb, followed by epilepsy. It is therefore possible that the paradoxical effects may be explained as follows: that the movements evoked in the left leg, in the first instance by stimulation, were due to insufficient narcosis.

Subsequent stimulation with a strong current of the leg area on the right side causes flexion and extension of muscles of the thigh and leg of the left side, and also of the right. None of the hallux and toe movements were obtained. It requires a much stronger stimulus to the right side of the brain than to the left to produce an effect. The animal was then killed with chloroform, the spinal cord and brain removed and placed in 2 per cent. solution of bichromate of ammonia. The seat of injury in the cord was not visible to the naked eye.

As previously stated, sections were prepared by the WEIGERT and PAL methods, after being imbedded in celloidin.

In this particular case every segment of the cord was cut, and photo-micrographs showing the extent of the lesion and the degenerations above and below were prepared, as shown in Plate 2. The microscopical examination of the *degenerations*, and the inferences derived therefrom, will be discussed later on.

Case IV.

Rhœsus ♀.—Left hemisection at the 6th dorsal segment, and insertion of a small piece of celloidin into the gap formed by the section.

1st day.—Temperature, right popliteal space, 100°·8 F.; left popliteal space, 100° F.; surface temperature, right foot, 88° F.; left foot, 93°·6 F. Complete paralysis of the left leg. No paralysis of the chest muscles noticeable.

When tested by electrical excitation the animal seemed to respond to a strong stimulus on both sides. It could not, however, localize on the left (paralyzed) side, whereas it immediately scratched the part on the right side. Testing the animal by this means, as well as by pricking with a needle, was very difficult, owing to its not being tame; but dipping the feet in hot water gave decisive results. The test was applied as follows :—A vessel containing hot water is raised so that the toes are gradually immersed. Both feet were withdrawn, but the left not so quickly.

4th day.—The animal is doing well. Sensibility tested by dipping the feet in hot water, resulting in immediate withdrawal of the right foot, and, after a second or two delay, withdrawal of the left foot. Knee-jerks present on both sides.

8th day.—Animal took some time to catch. The temperature of the right popliteal space was 103°·8 (the high temperature being probably due to the struggle). The thermometer was left in five minutes. While this was done, my assistant kept the left knee flexed, so that no exposure of surface occurred. Temperature of the left side was now taken, and the maximum rise was 101°·4 F. It might be thought

that the difference in temperature of the two popliteal spaces was due to the animal having remained quiet, and a fall in temperature thereby occurring; but the thermometer again placed on the right popliteal space registered 103°·6, showing that there was a *real* difference in the temperature of the two limbs, which could only be accounted for by a diminished heat production on the paralyzed side. Sensibility to the heat test same as before. Knee-jerks present on both sides.

10th day.—Collection of fluid at the seat of the injury evacuated. Movement has come back to a slight extent in the left (paralyzed) limb.

20th day.—Sensibility tested by dipping the feet in hot water; right foot withdrawn after $1\frac{1}{2}$ seconds; left foot after 3 seconds, so that there is still some delay. Left knee-jerk markedly exaggerated. Temperature, right popliteal space, 103°·8; left popliteal space, 101°·8; surface temperature of right foot, 86°; left foot, 80°: that is to say, the skin temperature on the paralyzed side is now lower than on the non-paralyzed, no doubt due to the fact that the vaso-motor paralysis has passed off, for the plantar surface of the foot is now neither swollen nor dry. The animal is frequently seen to flex both hip, knee, and ankle on the paralyzed side. It was put into the large cage to run about.

40th day.—Temperature, right popliteal space, 103°; left popliteal space, 102°·8. Muscles not very wasted; the animal runs about all over the cage; responds to hot water test on both sides.*

46th day.—The animal was etherised. The right motor area stimulated in the same manner as the last. With a moderate current arm movements readily obtained; leg, not at all. By increasing the strength of the stimulus, so that the current was very strong, flexion of leg at knee, and occasional movements of ankle, toes, and hallux obtained, and sometimes bilateral movements of legs. Stimulation of left motor area, with a moderate current, produced the usual movements of arm and leg very readily; with a very strong current, occasional movements of leg of the same side. The animal was then killed with chloroform. The cord was taken out. There was no sign of wound of the skin, and the bones had grown over the spinal canal. There was a small elevation on the side of the cord at the seat of the lesion. This cord was treated in exactly the same way as the last. A photo-micrograph of the lesion is shown in Plate 1. The degenerations above and below the lesion are in all respects the same as those of the last case.

Case V.

Large, tame, and very intelligent Rhœsus ♀. The 6th dorsal segment of the cord was exposed, and three transverse hemisections at a distance of two or three millims. apart were made on the left side.

1st day.—The animal paralyzed in both limbs. The *left* foot and leg are swollen, and the plantar surface of the former is redder and drier than that of the opposite side. There is much less hair covering the popliteal spaces of this animal than in the other animals experimented upon; perhaps this will account for the fact that there is only a slight difference in the temperature of the popliteal spaces of the two sides.

Sensation. (1). *To heat.*—The toes dipped in hot water were withdrawn almost immediately on the right side, on the left there was a longer delay.

(2.) *Pricking with a needle.*—The animal seemed to feel on both sides although it required a much sharper prick than usual before it would respond. All the way down the back it responded much sooner to a prick on the right side than the left.

Knee-jerks present on both sides.

3rd day.—There is considerable swelling of the wound, due to collection of fluid. A quantity of serous fluid evacuated by puncture.

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* This animal was not alive when I first introduced SCHIFF's clip test.

Sensation tested by pricking with a needle. The animal undoubtedly feels better on the right than on the left side; this was especially observed when the back was pricked. Heat test yielded the same results as before.

From this date the animal began to regain some power in the right leg.

13th day.—The animal can now stand by catching hold of the wire-work of the cage with its hands. There is still some fluid collected which was let out. It has power in all the muscles of the right leg and foot although there is some enfeeblement. There is only slight voluntary power in the left leg, and occasionally bilateral flexion and extension of the hip and knee joints have been noticed.

Temperature, right popliteal space	98°·6
,, left ,, ,, ...	98°·4

Sensory tests yielded the same results as before.

23rd day.—The animal was kept amused with raisins, and sensation was tested by myself and Dr. BRADFORD. It was observed that the animal would stop eating and give unmistakeable signs of interrupted enjoyment when the *right* side was pricked, whereas it took little or no notice when the left side was pricked. The foot, the leg, the thigh, and the back were tested.

The left leg still remains paralyzed, and the right somewhat enfeebled.

24th day.—Tested the sensibility of the animal with Professor SCHÄFER and obtained the same result as on the previous day.

32nd day.—Tested sensibility with the faradic current; the animal undoubtedly felt better on the non-paralyzed side.

35th day.—Tested the animal with Dr. SHERRINGTON; he came to the conclusion that the animal did not feel so well on the paralyzed side. The animal can now move the right leg well and hops about all over the cage, climbing the rope and running after the other animals. There is, however, very little movement in the left leg; occasionally I noticed a bilateral associated flexion of the hip and knee joints.

43rd day.—Tested the sensibility at a meeting of the Physiological Society. Pricking and the hot water test demonstrated the fact that the animal felt much better on the non-paralyzed side. Mr. HORSLEY recommended me to try SCHIFF'S clamp test, which I have since found invaluable.

44th day.—A small pair of clip forceps was fixed on the skin of the foot, leg, and back, its attention being attracted by my assistant to pieces of apple, so that the animal did not see what was being done. It immediately removed the forceps on the non-paralyzed side. Now, as it did not see the forceps, it could only have become conscious of their presence by the skin sensations produced. When the same forceps were applied on the paralyzed side in similar situations, the animal took no notice, but went on uninterruptedly grabbing at pieces of apple and raisins. The forceps were again applied to the right foot; the animal immediately ceased its efforts to obtain the fruit, and directed its attention to the cause of irritation, drawing up the right leg and pulling the forceps off with the right hand. On the paralyzed side the forceps were left on ten minutes without the animal taking any notice. I then removed them.

50th day.—Sensory tests yielded exactly the same results. Motor paralysis little or no improvement.

62nd day.—The animal occasionally seen to flex the hip, knee, and ankle joints of the left side, *e.g.*, in climbing. Independent contraction of muscles of the left leg has not been observed, even when the animal was lying on its back between my assistant's knees.

Sensory tests yielded precisely the same results as on the last occasion.

84th day.—The animal shown at a meeting of the Physiological Society, and the clip test demonstrated.

There is little more to be said about this animal, except that it remained alive until the 163rd day after the operation, when it was killed with chloroform. It regained very little power in the left limb, and *sensation as tested* by dipping the feet in hot water, by applying a test-tube containing hot water to the skin, by pricking with a

needle, and by the application of the clip, invariably yielded the same result as previously described.

It may, therefore, be concluded that in *this* animal sensibility to heat and pricking was greatly diminished on the paralyzed side, and little, if at all, affected on the non-paralyzed side. The sensations produced by the clip, which might be tactile as well as painful pressure sensations, were felt on the non-paralyzed, but not on the paralyzed side. Inasmuch as the animal removed the clip immediately and without even seeing it, it must be concluded that the muscular sense was unaffected on the non-paralyzed side.

The cord was removed and hardened in the usual manner. At the seat of injury a little nodule of fibrous tissue existed about as large as a small pea, limited, for the most part, to the left side, and firmly connected with new periosteal bone.

The microscopical examination of the cord at the seat of lesion, showed, on the left side, a complete destruction of all nerve tissue for about $\frac{1}{4}$ inch. It was replaced by a dense fibrous tissue, and the cord was so much damaged on the *left side* that the photo-micrograph of a section through the lesion shows quite a different appearance to most of the other lesions. The grey matter on both sides is also almost completely destroyed, and the natural configuration of the two anterior and two posterior cornua is lost, so that it would be difficult to recognise the photo-micrograph as one of the spinal cord. However, the right dark portion, shown in photo-micrograph 6, Plate 1, consists of medullated nerve fibres, for the most part undegenerated. There is, therefore, at the seat of lesion, a *complete destruction of grey matter on both sides, and the whole of the left lateral half of the white matter*. This is proved by photo-micrograph 7 showing the degenerations just above the lesion.

Further microscopical examination of the cord of this case showed a well marked degeneration in the antero-lateral tract on both sides, extending up to the medulla, but more marked on the side of the lesion. There was also a small area of degeneration in the right posterior median column. The injury of the two anterior columns, and the slight return of movement, as compared with the other animals, agree remarkably with the results obtained by HOMÈN* (*vide* p. 20).

The almost complete destruction of the grey matter at the seat of the lesion, and the loss of sensibility on the left side, with perfect retention on the right side (that is the side with the lateral and posterior columns for the most part intact), suggests the probability that conduction of sensory impulses may take place, partly in the grey matter, and partly in the white matter, for inasmuch as the grey matter was almost completely destroyed on both sides, and the white matter completely on the side of the injury, *no channel was left for conduction of impulses in the left side* while the white matter still remained on the right side, hence the perfect retention of sensibility.

* HOMÈN: 'Contribution Expérimentale à la Pathologie et à l'Anatomie Pathol. de la Moelle Epinière.' Helsingfors, 1885.

Case VI.

Rhœsus ♂.—The spinal cord was exposed about the 6th dorsal, then a median incision was made and a small blunt instrument introduced so as to destroy the central grey matter. The next day the animal was apparently none the worse, there being no paralysis and no loss of sensation.

Ten days later the cord was again exposed and a hemisection made upon the left side at the 6th to 7th dorsal segment. This was followed by complete paralysis on the left side.

1st day.—Temperature of right popliteal space much higher than the left. Feet dipped in hot water; the animal showed signs of feeling on both sides.

7th day.—The same result.

16th day.—Clip test applied. Immediately removed from the right side, not from the left. The animal etherized, and a clip placed on the sole of each foot. When it recovered consciousness it removed the clip from the right non-paralyzed foot, leaving the other hanging on.

28th day.—Bilateral movements returning. Clip test, same result as before.

39th day.—Anæsthetized with ether. Faradic stimulation of the motor region of the right hemisphere with a moderate current evoked the usual movements of the left arm and hand, but stimulation of the leg area produced no movement whatever of the left leg, even when the stimulus was increased so much as to be unbearable when the electrodes were applied to the tip of the tongue; frequently, however, a movement in the muscles of the thigh, leg, and foot of the *same* side was observed.

The animal was then killed with chloroform, and the cord removed and hardened in the usual manner.

Photo-micrograph 6, Plate 1, shows the complete destruction of one-half of the cord at the seat of the lesion.

Case VII.

Hemisection of the cord at the level of the 3rd dorsal on the *right* side. After the section had been made a blunt probe was pushed into the gap formed, so as to complete the severance of the nerve structures.

1st day after operation.

Temperature right popliteal space	98°
,, left ,, ,, ...	99°·8

The right foot was dry and swollen, but the temperature could not be obtained on either side.

Sensory Test (*Hot Water Test*).—The animal feels on both sides when the feet are dipped in hot water.

Pricking with a Needle.—Pricking about the root of the tail is felt and localized much better on the left (non-paralyzed side) than the right; moreover, a muscular reflex is excited much more readily on the left side than the right.

Complete paralysis of the right leg.

4th day.—Tested the animal with Dr. SHERRINGTON, who considered that the animal felt better on the non-paralyzed side. Knee-jerk exaggerated on the paralyzed side.

13th day.—Clip test applied for the first time. My assistant attracted the animal's attention with pieces of apple while I applied the forceps to the skin of *the paralyzed foot. No notice was taken of this for some time. Then the left non-paralyzed foot was lifted up, inspected, and scratched in exactly the same situation as that to which the forceps were hanging on the other foot.* This manœuvre was repeated several times, but no attempt was made to remove the clip from the paralyzed foot. The animal then began to struggle, it saw the forceps and immediately removed them. When it was quite quiet again and occupied in obtaining pieces of apple, unobserved by the animal I placed the pair of clip forceps upon the non-paralyzed foot. The animal immediately drew up the leg and took them off. The animal was

now etherized, and when the conjunctival reflexes were just abolished the knee-jerks and plantar reflexes were tested. It was observed that on the left non-paralyzed side the knee-jerk came back and was somewhat exaggerated long before any evidence of it could be obtained on the right paralyzed side. The plantar reflexes could not be tested to my satisfaction. Two similar clip forceps were fixed one on the plantar surface of each foot whilst the animal was under the influence of the anæsthetic. When the animal recovered from the anæsthetic it removed the forceps from the non-paralyzed foot, but took no notice of the other pair attached to the sole of the paralyzed foot. After leaving the forceps some time attached I removed them.

25th day.—The animal can now run about and use its right leg.

31st day.—The animal placed under an anæsthetic. It was thought that the knee-jerk still returned sooner on the non-paralyzed side. A clip was placed upon the paralyzed foot while it was unconscious; when it came to, the animal imagined there was something irritating the non-paralyzed foot, drew it up, examined it several times, and bit and scratched the identical spot on the sole of the foot to which the clip was hanging on the other foot (*Allochiria*).

Temperature 1° higher on the left popliteal space than the right.

47th day.—Very difficult on casual observation to believe that the animal had suffered any injury. On close inspection it might be noticed there was a delay in the movements of the right leg, but it can grasp objects. When springing on to the bar the animal seizes it first with the left foot, then somewhat slowly draws the right up afterwards. In walking or running it is difficult to notice any delay, and in purely bilateral springing movements no delay was observable. The animal, when lying on its back between my assistant's knees, would flex the hips and knees of both sides, flex the ankle of the uninjured side and slightly invert the same, whereas on the injured side the ankle would not be flexed nor inverted, and the grasp was either not present or very much enfeebled.

It is possible that this loss of grasp in the foot is associated with loss of tactile sensation.

Sensibility to heat and pain, tested in the usual manner, was perfect on both sides.

Clip Test.—Now removes the clip from the paralyzed foot, but only after a very considerable delay. It is immediately removed from the non-paralyzed foot.

The animal continued to improve, and on the 107th day was tested as to sensibility. The reaction to heat and to pricking was apparently normal. The clip is now removed from the right (paralyzed) foot almost as soon as from the left. It was anæsthetized, and the whole of the *leg area of the cortex cerebri on the right* side removed. The next day the animal was found sitting up, and quite recovered from the shock of the operation. The animal is found to be completely paralyzed in the left (previously non-paralyzed) leg. The right (formerly paralyzed leg) retains as much movement as immediately before the operation. The skin of the left foot feels neither hot, dry, nor is it swollen. A clip placed upon the left foot produced no facial signs indicating that the animal felt, whereas, when attached to the right foot, it showed plainly that it felt, and in less than 30 seconds drew the leg up and removed it. The feet dipped in hot water successively, the animal responded much more readily with the right foot than the left. Similarly, pricking caused more excitement of the animal on the right side than the left; in fact, it took very little notice when the left side was pricked.

Temperature in right popliteal space . . .	100°·2.
,, left ,, ,, . . .	99°·4.

That is, the reverse of what it formerly was.

The animal remained in this condition for 8 days, when it was killed with chloroform.

The spinal cord was removed, hardened, and sections of it made in the usual manner. The lesion itself is not shown in Plate 1, but a photo-micrograph of a section of the cord just above the lesion, showing the ascending degenerations and the shrinkage to nearly half its size of right side. When the cord was taken out, the seat of the lesion was evidenced by a small fibrous nodule, situated on the right

side of the 3rd and 4th dorsal segments of the cord. The brain and portion removed have been preserved. The reason why the actual lesion of the spinal cord is not shown in Plate 1 is because, in trying a new method of making sections of the lesion, I spoiled the specimen.

Case VIII.

Large Rhœsus, ♂. Hemisection of the spinal cord at the 3rd cervical segment on left side. Two cuts made at a distance of 1–2 millims. apart. Some hours afterwards the animal was examined to ascertain the resulting paralysis. The arm and leg of the left side were completely paralyzed. There was vaso-motor paralysis of the vessels of left foot and hand, noticeable by the increased vascularity, and a marked increase in the surface temperature of the skin of the foot on the paralyzed side. The left pupil was not more than half the size of the right.

No appreciable difference noticed in the contraction of the abdominal and thoracic muscles during respiration while the animal was lying dozing on my assistant's lap.

1st day.—The animal sitting up, but appears drowsy. The left leg and arm are paralyzed, the right abdominal and thoracic muscles act more powerfully than the left, but there is no palpable asymmetry of the chest.

On placing the right and left index fingers respectively under the left and right hypochondriac regions of the animal, so as to be able to feel the impulse of the descending diaphragm during inspiration, it was observed that on the right side the impulse was more feeble; but this may be due to the presence of the liver, which offers a more solid resistance to the point of the finger. The left lung is resonant all over.

Left foot swollen, dry, darker in colour and hotter than the right; with the surface thermometer* the former registers 10° F. more than the latter. The temperature in the popliteal space, taken with a quick-registering mercurial thermometer, registered 2° F. higher in the right side than the left.

Sensation.—Hot Water Test.—The *right foot* is almost immediately withdrawn; the animal localizes the sensation by scratching the part.

The *left foot* (paralyzed) withdrawn quite as soon as the right by struggles of the body.

Clip Test.—Placed upon the sole of the *right foot* immediately removed by the right hand.

Placed upon a similar spot on the *left foot*, the animal took no notice for some time; then it became aware of some cause of irritation, and it lifted up the opposite foot and examined it (*Allochiria*) several times, but made no attempt to examine the foot to which the clip was attached.

When placed upon the palm of the left hand, it removed it in a few seconds; probably it saw me attach the clip.

2nd day.—*Pricking with a Needle.*—No result obtained when the soles of the feet are pricked. An occasional response when smartly pricked upon the legs of either side. About the root of the tail pricking gave rise immediately to evidence of feeling on both sides.

When the animal was turned round so as to present the back, the face being covered by my assistant, it showed more evidence of feeling when pricked on the right side than on the left.

Left pupil is a little smaller than the right, but the difference is not so marked as yesterday.

Knee-jerk is absent on the paralyzed side, it is slight but distinct on the non-paralyzed side.

3rd day.—Left linea alba pulled over slightly during inspiration.

Vaso-motor paralysis passing off, skin of foot moist.

Swelling gone, no marked difference in surface temperature.

Temperature, right popliteal space	100°·2
" left " "	98°·8

* The surface thermometer, when held against the skin for three minutes, never registers the temperature of the blood, but it serves as a comparative test if it be applied for the same period of time.

Left arm and leg paralyzed completely. Pupils equal, both react equally to light and accommodation. Wound healed all along by first intention.

Sensation. Pricking with a Needle.—The animal exhibits evidence of feeling on both sides.

Clips.—Placed on the palmar and plantar surfaces of the left side produced no effect upon the animal, and although each limb was placed close to the right hand, no attempt was made by the animal to remove the clips. When tranferred to similar points upon the right side they were immediately removed.

Knee-jerks exaggerated upon both sides.

4th day.—Descent of the diaphragm on the left side produces a much stronger impulse against the finger, in fact it is nearly as strong as the right.

Sensation.—Pricking the root of the tail produced facial evidence of feeling on both sides, more marked on the non-paralyzed side. No reaction elsewhere, although usually obtained in a healthy Monkey.

Hot water, in a test-tube, applied to the plantar surface of the foot, caused the animal to show signs of feeling on both sides.

Clip Test.—The same as yesterday, except that after a considerable delay it was removed from the left hand; possibly it saw the clip.

Frequent bilateral associated movement of left leg in struggling to get free, this was never noticed in the arm.

Temperature, right popliteal space	100°
„ left „ „	97°

12th day.—The animal in very much the same condition except that there is more associated movement of the left leg.

29th day.—The animal can stand and moves left leg, flexing and extending all the joints. The knee-jerk is absent on the paralyzed side. No movement of arm and hand noticed.

Sensation.—Hot water test responds on both sides.

To the prick of a needle the animal seems to be slightly hyperæsthetic on paralyzed side.

Clip test.—The clip is removed after delay on both sides. The animal was anæsthetized and the motor area of the cortex cerebri exposed on both sides.

[Examination of the spinal cord in this case showed, not only the ordinary degenerations above and below the lesion, but a well marked scattered degeneration of the posterior column with the exception of the root zone extending right down the cord into the lumbar region. The cause of this I am unable to state; there was no appearance of meningitis.—*Dec. 5th*, 1891.]

Results of Stimulation.

	Situation.	Faradic current.	Left motor area.	Right motor area.
1	Marginal opposite ascending parietal convolution	Moderate*	Movement of right leg	Nil
		Strong	. . . .	Nil, but occasional contraction of trapezius and sternomastoid from the spread of the current
2	Marginal opposite posterior end of sulcus x	Moderate	Trunk and leg movements on right side	
		Strong	. . . .	Nil
3	Marginal opposite anterior end of sulcus x	Moderate	Movements of shoulder and upper part of right side	Movement of shoulder of (*right*) same side
4	Marginal a little further forward still than previous	,,	Bilateral movements of both shoulders and ears, and downward of eyes	
		Weak	. . . .	Nil, except downward of eyes
5	Right side of brain above sulcus x, anterior part	Moderate	Contraction of shoulder muscles	Contraction of shoulder muscles
	Left side of brain above sulcus x, anterior part	,,	*Ditto*	*Ditto*
6	Over middle of x	,,	Contraction of shoulder muscles only more marked	Contraction of shoulder muscles
7	Just below anterior end of x	,,	Shoulder	Shoulder
8	Ascending parietal below level of x	,,	Extension of fingers	Nil
9	Ascending frontal below x	,,	Shoulder movements and flexion of fingers	Shoulder movements as before
10	Opposite middle of x	,,	Shoulder	Shoulder
11	Above the angle of precentral sulcus	,,	Contraction of neck muscles, retraction of ear	Slight contraction of trapezius and lateral deviation
12	Ascending parietal, opposite line of L of precentral	Strong	. . . .	Quivering movement of thumb and index, sometimes followed by epilepsy
		Moderate	Extension of fingers, flexion of thumb	
13	Ascending frontal, opposite L of precentral	,,	Movements of shoulder and flexion of fingers	Strong movement of shoulder followed by epilepsy
14	Marginal opposite ascending parietal	*Strongest*	. . . .	*Nil*
		Moderate	Movement of foot and hamstrings	
15	Corpus callosum, opposite front of x	,,	Nil	Nil
	,, ,, middle of x	,,	Movements of shoulders	Shoulders and arm

Nothing else could be obtained.

* Sharp sensation produced on the tongue by the fine-pointed electrodes, but not unbearable.

Case IX.

Rhœsus ♂.—Hemisection of cord at level of 6th to 7th dorsal, on the left side.

Two sections made at a distance of two millims. apart; the membranes were opened in order to find mid line.

1st day.—Pricked about root of tail; *responded on paralyzed side, but not on the non-paralyzed.* On the abdomen responded to a prick on the non-paralyzed side, but not on the paralyzed side.

Feet dipped in moderately hot water, not much notice taken; if anything, more on the paralyzed side.

Pricked upon the right non-paralyzed leg the animal was observed to scratch the part, but not on the opposite side.

Clip Test.—A clip placed upon each foot, the one on the non-paralyzed side removed after a few minutes, the other was left attached, without the animal taking any notice. The clip was then fixed so as to compress the nail; it was removed from the *non*-paralyzed side after a few minutes, but not from the paralyzed side until it was shown to the animal.

3rd day.—Responds on both sides to prick of a pin, or to dipping feet in hot water.

The clip placed upon the paralysed foot is undoubtedly felt, but not removed. When placed upon the non-paralyzed foot it was usually taken off almost immediately. It was noticed afterwards when the clip was transferred from the non-paralyzed foot to the paralyzed, that the animal examined the foot of the non-paralyzed side several times (*Allochiria* evidence again, as in other cases of *associated sensation*).

11th day.—It takes little or no notice of a prick *on the non-paralyzed side,* but appears hyperæsthetic on paralyzed side.* The feet dipped in hot water, evidence of feeling on both sides, more marked on paralyzed side. A clip placed on the non-paralyzed foot, with the head covered so that the animal could not see, was immediately removed—a clear proof that it felt and localized the sensation. When placed on the paralyzed foot an *associated sensation* was produced in the same spot of the opposite foot. The animal raised and examined the foot, and scratched the part corresponding to the point of attachment of the clip on the opposite side.

19th day.—Paralysis of left limb; sensory tests yield exactly the same results as on the last occasion.

35th day.—Pricked with a pin, feels on both sides, scratches the limb on non-paralyzed side at point irritated. The toes dipped in hot water, the foot is withdrawn immediately on both sides. The clip placed upon the right non-paralyzed foot is immediately removed, but only after some few minutes from the paralyzed foot. It can move hip, knee, and ankle of paralyzed side, but makes no attempt to grasp with the left foot.

The animal was killed with chloroform and the cord removed; it was destroyed for $\frac{1}{3}$ inch on the left side at the level of 6th to 7th dorsal segments. Sections were prepared after hardening in the usual manner. (*Vide* photo-micrograph, Plate 1.)

Examination of the microscopical sections from this case showed complete destruction of the grey matter at the seat of the injury, with hæmorrhages and exudation of plasma. The posterior column and the anterior and lateral columns of the left side were completely destroyed. The posterior column of the

* Note in connection with this case.—The animal was apparently hyperæsthetic on the paralyzed side to the pricking of a pin, and there seemed to be diminished sensibility on the opposite non-paralyzed side; but I have found that some animals when frightened take no notice of pricking with a needle, and again, the fact that the animal removed the clip from the non-paralyzed side, on all occasions, showed conclusively that it was conscious of a sensation, which led to a purposive act, dependent for its execution upon the higher volitional centres.

If the clip had not produced a painful as well as tactile sensation, it is difficult to understand why the animal should have removed it on all occasions.

right side was partially injured, and contained a great many degenerated fibres. The anterior and lateral columns also contained many degenerated fibres.

Sections above the lesion showed well-marked degeneration of the left posterior column and the antero-lateral and direct cerebellar tracts. There was also degeneration visible to the naked eye of the right posterior column and antero-lateral tracts, and scattered degeneration of the direct cerebellar tracts.

The *results* of these experiments may be placed under the following headings :—

I. Motility.
II. Sensibility.
III. Vaso-Motor and Temperature.
IV. Degenerations.
V. Cortical Stimulation.

I. *Motility.*—The return of movement in the paralyzed muscles was dependent upon the extent of the bilateral associated action, consequently, muscles that invariably act in conjunction with the muscles of the other side were but little affected, and it was difficult to observe any paralysis of the thoracic and abdominal muscles after hemisection in the dorsal, and even the upper cervical region. The dilatation of the pupil, which occurred in hemisection of the cord at the 3rd cervical, had passed off by the third day. The contraction of the diaphragm was, presumably, weaker on the left side for a few days, but this may have been apparent rather than real, for the liver on the right side would descend more forcibly against the finger than the more yielding structures on the left side. With one exception (Case V.), movement returned in the muscles of the leg to such an extent that the animal was able to spring from one bar to another, to climb the wire netting of the cage, and to run about as actively as a Monkey whose spinal cord was intact. In Case V. (the exception) the injury was not limited to the left side; moreover, sensibility never returned in the left leg sufficiently for the animal to be aware that the clip was pinching its foot. It occasionally responded feebly to the pricking on that side, but it seemed quite unconscious of tactile impressions. This may partially account for its not recovering motion in that leg to the same extent as the other; but since the right leg was also enfeebled, it was probably also due to the opposite side having been damaged by the compression of the fluid which collected, and was evacuated on several occasions. On an average at the end of three weeks, movements of hip and knee return on the paralyzed side; they are usually *associated movements* of flexion and extension; flexion and extension of ankle accompanies these movements when occurring in walking, climbing, or springing; but when the animal is lying on its back between my assistant's knees, all the joints of the lower limbs may be flexed except the ankle on the paralyzed side, which is extended apparently by the weight of the foot. The grasp, except in associated actions, such as climbing, holding on to the bar or the wire of the cage, was as a rule not noticed even many months after the

operation—for example, the animal would never grasp the finger with the paralyzed foot, although it would do so with the non-paralyzed. The muscles on the paralyzed side were somewhat flabby and wasted, but always responded to faradism, and after death, when examined microscopically, appeared quite normal. I shall have occasion to refer to the probable cause of return of motor function, when speaking of the motor paths.

WEISS* operated on young Dogs, making hemisections at the juncture of the dorsal and lumbar regions, and took all precautions to make a complete division of one half of the cord in this region. At the end of the first, second, or third week a return of motility occurred in the paralyzed leg, which took an active part in voluntary associated movements. In some cases the motility had recovered to such an extent after three or four weeks that it was difficult to discover which of the two lower extremities was the more moveable one, because the previously paralyzed leg moved quite normally in walking and running; but in rapid movements, as when hunted about the room, the animal sometimes fell over towards the paralyzed side. These experiments quite accord with mine. A Monkey, however, is much higher in the zoological scale, and owing to certain actions in this animal being of a unilateral character, especially the finer movements of the foot and hand, a more or less permanent defect in motility ensued for these actions.

GOLTZ† has almost completely removed the left hemisphere in Dogs. One of these animals I had the opportunity of seeing at the Physiological Congress held at Basle, September, 1889. The brain of this animal has been carefully examined by LANGLEY and GRÜNBAUM. They state that "the left hemisphere is almost completely removed." "The left pyramid is much reduced in size and almost completely composed of dense connective tissue." Although this animal had been deprived of almost the entire left hemisphere, yet there was hardly any motor defect in the right limbs. GOLTZ demonstrated that the animal possessed voluntary power over the right limbs by burying pieces of meat in a box of pebbles; the animal would use its left foot to dig out the meat, but if it were prevented from using the left foot, it would at once apply the right foot to scrape out the meat.

WEISS also made the following experiments: Hemisection at the level of the last dorsal and first lumbar in the Dog; after twenty-five to forty-one days respectively, in two cases, recovery of movement and of sensation had taken place. A left hemisection was then made above the previous lesion. In both cases, complete paralysis and anæsthesia of the lower extremities, with paralysis of the bladder and large intestine, supervened. These phenomena persisted and no change had occurred after fifteen and six days respectively. The animals were then curarized. After cutting through the vagi, the sciatic nerves and brachial plexuses on both sides were

* Vienna Academy, 'Sitzber. Math.-nat. Classe,' 1879 (vol. 80, Abth. 3, p. 340).

† 'Journal of Physiology,' vol. 11. ("On the Degeneration resulting from removal of the Cerebral Cortex and Corpora Striata in the Dog," by J. N. LANGLEY, F.R.S., and A. S. GRÜNBAUM.)

stimulated. No increase of blood-pressure occurred on stimulation of the sciatic, but distinct increase of blood-pressure on stimulation of the brachial plexuses. The spinal cord was laid bare and stimulated with electricity. Distinct jerks in the fore legs occurred, none in the hind legs. Lastly, the lumbar spinal cord was stimulated, causing violent jerks of the lower extremities, which proved that the obstruction was caused by interruption in the conduction of the white matter. Experiments made by OSAWA* in the main confirmed the results obtained by WEISS. According to OSAWA, the diminution of sensibility was rather more marked on the side of the lesion. (HOMÈN, *loc. cit.*)

M. KUSMIN,† after hemisection at the 6th cervical vertebra, believes that he has proved, besides paralysis of the limbs on the side of the lesion, a loss of sensibility of the hind limb on the opposite side, and a slight enfeeblement of sensibility of the anterior limb of the same side. (HOMÈN, p. 22, *loc. cit.*)

HOMÈN‡ has made a number of careful experiments upon adult Dogs, 52 in all. Antiseptic precautions were used. The operations performed were :—

1. Complete hemisection.
2. Hemisection, sparing the anterior columns.
3. Hemisection, but also involving the opposite side somewhat, the injury extending across the mid line so as to cut the opposite anterior column.

The animals were kept alive from two days up to nine months. Movement returns after a variable period of time in the hind limb on the side of the injury. The movements will return much sooner if the anterior columns are uninjured. HOMÈN concludes that his experiments favour the view that the anterior columns are motor.

With regard to sensibility, tested by pressure, pinching, pricking, and faradic excitation, the results agreed with those of WEISS. After the shock of the operation had passed off, no diminution of sensibility could be detected in the hind limbs, as compared with the fore limbs. Sometimes there was a slight exaggeration of sensibility on the side of the lesion.

Section of the posterior columns did not seem to prevent nor even to influence the transmission of sensory impressions.

HOMÈN made very careful microscopical examination of the spinal cord of the animals, and noted the histological changes resulting from the hemisection.

BORGHERINI§ made a section of the lateral column on one side of the upper portion

* OSAWA: 'Untersuchungen über die Leitungsbahnen im Rückenmarke des Hundes.' (Thesis Strasburg, 1882.

† KUSMIN: "Exp. Untersuchungen über die Leitungsbahnen im Rückenmarke des Hundes." 'Med. Jahrbuch.' Wien, 1882.

‡ HOMÈN: 'Contribution,' &c. 1885.

§ "Beiträge zur Kenntniss der Leitungsbahnen im Rückenmarke," von AL. BORGHERINI. 'Mittheilungen aus dem Institut für Allgemeine und Experimentelle Pathologie in Wien.' (*Referat* in 'Neurologisches Centralblatt,' 1887.)

of the lumbar spinal cord of Dogs. Paralysis of the hind leg of the same side occurred. After some weeks motility returned; the lateral column on the opposite side was then cut through, motor and sensory paralysis of both hind legs occurred. This agrees with the results which I obtained in Case I., in which hemisection was performed in the upper dorsal region resulting in paralysis of the lower limb on the same side, sensation to pricking, heat, and galvanism persisting. Motility had returned by the fifth week, quite perfectly as regards all bilateral associated movements. A section of the lateral column on the opposite side produced complete paraplegia as long as the animal lived, and great diminution, though probably not abolition, of sensibility.

In another series of experiments by Borgherini, only the anterior column remained intact, and he concludes that the restoration of motility and sensibility can be brought about only by collateral tracts in the anterior column. This subject will be discussed after I have considered the degeneration found in the cords.

Sensory symptoms.—When tested by *heat, pricking,* and *stimulation by faradism,* it was very difficult to decide, *except in one case* (V.), whether the animal felt better on the side of the section or on the opposite side. There was usually a delay before the animal responded on the paralyzed side, and some considerable time (generally two or three weeks) would elapse before the animal would correctly localize the part pricked or stimulated. On the non-paralyzed side the day after the operation the animal, when tested, was often noticed to scratch the part irritated, and try with its hand to remove the cause of irritation—a certain sign of conscious sensation and localization. In Case V., the large tame Rhœsus, there was almost complete abolition of sensation to heat and pricking on the paralyzed side. This may be explained by the almost total destruction of one-half of the cord for some little distance, and the extensive degeneration of the anterior column of the opposite side. In two cases where the dura mater was severed, so that the two cut surfaces of the cord gaped, there was apparently sometimes hyperæsthesia on the injured side.

The clip test applied to most of the animals was the most valuable sensory test. It invariably showed the same result, viz., that the clip was not removed from the paralyzed foot, but always removed from the non-paralyzed, although various means were adopted by which the animal could not possibly have seen the clips applied, such as application while the animal was unconscious with ether; application while the animal's head was covered by my assistant's coat; application while the animal's attention was engaged with raisins or apples; but the result was always the same. The animal for some weeks after the operation always removed the clip from the non-paralyzed side, and never from the paralyzed, unless it happened to see it. In Case V. the animal only recovered movement and sensibility in the left leg to a very limited degree, and the clip test remained the same throughout the five months that the animal lived. The peculiar condition of *Allochiria* noticed in nearly all cases

when this test was applied is of great interest, and, as I shall show later, affords considerable indirect proof of the course of the sensory fibres.

Reflexes.—I can say nothing very definite about the superficial reflexes; concerning the knee-jerks, however, it may be stated generally that for some days after the operation they were, as a rule, abolished, and eventually exaggerated, on the side of the lesion, except in Case VIII.

Vaso-motor and Temperature.—There was temporary vaso-motor paralysis on the side of the injury, which passed off completely within a week or two. The temperature of the popliteal space on the paralyzed side was lower by 1°–3° than on the non-paralyzed side; as movement returned in the limb on the side of the injury, so this difference diminished, until after some months there was hardly any difference in the two sides. The plantar surface of the foot of the paralyzed side was always dry, somewhat swollen, darker, and hotter to the hand than the opposite foot. The surface thermometer registered, when applied for the same periods of time, some 5° F. more on the paralyzed foot than on the other. When the vaso-motor paralysis passed off, the plantar surface on the side of the injury became cooler to the feel, and registered several degrees less than the other side.

In the popliteal space the temperature depends upon thermogenesis in the muscles, and the skin being covered with hair, little thermolysis takes place there. Consequently, the vaso-motor paralysis does not make itself felt owing to the comparatively trifling quantity of blood flowing to the skin of this part. The paralysis of the muscles causes a deficient thermogenesis, and it is this which causes the fall of temperature, as proved by the fact that, with return of movement, there is a rise of temperature to the normal.

The plantar surface of the foot, however, is supplied with sweat glands and a large supply of cutaneous blood-vessels. The hemisection of the cord paralyzes the vaso-motor nerves and the sweat glands, causing increase of blood to the part and deficient elimination of heat by cutaneous evaporation of sweat, hence an increased surface temperature. After the vaso-motor paralysis has passed off there is a fall of the surface temperature. A smaller quantity of blood flows to the part because there is a diminished metabolism occurring in structures functionally inactive (the foot muscles regain very little power).

The results of cortical stimulation of the brain after hemisection may be summed up as follows:—On the side opposite to the lesion *the leg area* of the cortex cerebri required a very strong current to produce any effect, the movements produced were leg movements (once hallux in one case), sometimes no effect could be obtained, even with a strong current; as often as not movements of the leg of the same side were observed. In the case where the section of the cord was made at the level of the third cervical, no movements could be obtained except shoulder movements.

The extent of the lesions and the resulting degenerations are represented in Plates 1, 2, and 3.

After careful examination of the spinal cords, especially of Case III., facts were elicited with regard to degeneration, which in the main confirm those of previous observers, SINGER,* HOMÈN,† and TOOTH.‡

Case III. was the most complete hemisection in which the injury was limited to one side (*vide* 4 and 5, Plate 1). A very small portion of the posterior median column alone has remained, and this is in great measure degenerated. Plate 2 illustrates this lesion, and the resulting ascending and descending degenerations.

The comma-shaped degeneration, visible to the naked eye in the posterior column, on the side of the lesion, for 0·5 centim. below the lesion (*vide* Plate 2, No. 20, and Plate 4, fig. 10), can be traced down for about 2 centims., the degenerated fibres gradually becoming less and disappearing altogether. I examined a large number of sections, to be sure about it, and I *invariably* found degenerated fibres in the posterior column, on the side corresponding to the degenerated pyramidal tract, and this agrees with the results obtained by HOMÈN§ on the Dog, and TOOTH‖ figures it after hemisection in the cervical cord of the Monkey.

On comparison of the degenerated area with the corresponding area on the opposite side, I was led to believe that the patch of sclerosis was due to a disappearance of a bundle of rather fine medullated fibres. RAMON Y CAJAL¶ and KÖLLIKER** have shown that the fibres of the posterior column, before they enter CLARKE'S vesicular column, divide into an ascending and descending set of medullated fibrils. This may be the explanation, or possibly these fibres are vertical commissural connections between the cells of CLARKE'S column. In cases where the lesion had not involved the posterior column so completely this degeneration was absent.

A number of thin sections of the cord, from this case and from No. IV., stained by PAL'S method, were examined with $\frac{1}{2}$-in. Ross and a very high magnifying eye-piece, by which combination a very large field with a sufficiently high magnification and precise definition was obtained.

Below the lesion the direct cerebellar tract fibres were observed undegenerated at the periphery of the cord outside the pyramidal tract, as low as the 10th–11th dorsal segment (*vide* fig. 6, Plate 4).

* "Über secundäre Degeneration im Rückenmarke des Hundes." Von Dr. J. SINGER, Assist. am Physiol. Inst. Prag. Aus dem 84. Bande der 'Sitzb. der K. Akad. der Wissenschaften,' III. Abth. October Heft. Jahrg. 1881.

† *Loc. cit.*

‡ *Loc. cit.*

§ *Loc. cit.*

‖ *Loc. cit.*

¶ 'Anatomischer Anzeiger,' 3, 4, 1890.

** "Zur feineren Anatomie des centralen Nervensystems.—Zweiter Beitrag. Das Rückenmark," von A. KÖLLIKER. Separat-Abdruck aus 'Zeitschrift für Wissenschaftliche Zoologie,' vol. 51, 1891, p. 1. Leipzig, WILHELM ENGELMANN.

Only a few had reached the periphery at the level of the 10th dorsal, while at the 11th there were hardly any undegenerated fibres of the cerebellar tract at the periphery, but numbers of large fibres could be seen scattered through the degenerated pyramidal tract, and especially taking a course close to the lateral border of the posterior horn (*vide* figs. 6 and 7, Plate 4).

At the 12th dorsal the large direct cerebellar fibres were found mostly in the angle between the anterior and posterior horns, close to the grey matter, some few among the degenerated pyramidal fibres, and none at the periphery. This entirely bears out some previous experiments of mine, in which I endeavoured to show that the cells of CLARKE'S column give off fibres which pass upwards and outwards through the lateral column to reach the periphery. Vertical incision into CLARKE'S column in the lower dorsal region on one side showed on the side of the section these same large fibres (belonging to an ascending tract degenerated among the healthy pyramidal fibres), and in the 7th dorsal region they arrived at the periphery. (*Vide* 'Brain,' 1891, "The Bipolar Cells of the Spinal Cord and their Connections.")

In Plate 2 this course of the fibres of the direct cerebellar tract is particularly well seen just above the lesion at the level of 5th dorsal. There will be observed along the lateral border of the posterior horn a well-marked sclerosis which separates the undegenerated pyramidal tract from the posterior cornu. A little higher this is seen considerably diminished, and still higher at the level of the 4th dorsal, the photograph shows that all the degeneration is at the periphery.

If the hemisection is made at the level of the 3rd dorsal this degeneration along the lateral border of the posterior horn is not so well marked, presumably because CLARKE'S column is not well marked higher up in the dorsal region. (*Vide* a paper by me in the 'Journal of Anatomy and Physiol.,' 1888, "CLARKE'S Column in Man, the Monkey, and the Dog.")

I think these results strongly support the old views of FLECHSIG upheld by KÖLLIKER,* that the cells of CLARKE'S vesicular column are connected not with efferent fibres, but with an afferent system. The nerve processes of the cells of this column run upwards and outwards to form the direct cerebellar tract of the same side.

Another fact worthy of notice is the way in which the degenerated cerebellar tract leaves the periphery in the upper cervical region. Professor SCHÄFER tells me that this quite agrees with his observations in conjunction with FRANCE† on descending degenerations resulting from cortical ablation. Many of these fibres which, in the upper cervical region, lie outside the direct cerebellar tract are of the pyramidal system.

I am also indebted to Professor SCHÄFER and Dr. SHERRINGTON for information as to the presence of a direct pyramidal tract in Monkeys. The former states that he

* *Loc. cit.*

† "On the Descending Degenerations which follow Lesions of the Gyrus Marginalis and Gyrus Fornicatus in Monkeys." By E. P. FRANCE, 'Phil. Trans.,' 1889, B.

has not observed degeneration in the anterior median column after extensive cortical ablations producing most marked degeneration of the crossed pyramidal tract. The latter observer has informed me that he has never seen degenerated fibres below the 3rd cervical, and the fact that they occur as low as this he accounts for by a prolongation of the pyramidal decussation.

We may consequently assume that in the Monkey there is no direct pyramidal tract in the dorsal region, and that degeneration which occurs below the hemisection in the anterior median and anterior columns, is not the result of direct pyramidal fibres, but of vertical commissural fibres between the nerve processes of cells of the anterior horn and the grey matter at different levels.

KÖLLIKER* states that the motor root fibres arise by a single nerve process from large and small nerve cells at all parts of the anterior horn, which nerve process in certain cases (according to GOLGI always) gives off lateral branches.

Inasmuch as there is complete degeneration of the anterior column immediately above and below the section, and this degeneration afterwards is found at the periphery and in the median fissure for a considerable distance above and below the lesion, gradually becoming less as the distance increases, and inasmuch as I have shown that all these fibres are not pyramidal, it must be conceded that they probably form vertical commissural connections between the cells of the anterior horn at different levels; but many of these fibres can be observed to decussate in the anterior commissure, thus bringing into co-ordinate relation the cells of segments above, below, and on the opposite side. Degenerated fibres could be observed in the anterior column as low as the sacral and even coccygeal region after a hemisection in the dorsal region, thus showing that far remote groups of cells are brought into relation (fig. 1, also *vide* Plate 4, fig. 9).

It may be, however, that there are long tract fibres both from the cerebellum and cerebrum in the antero-lateral column. MARCHÉ† asserts that efferent fibres from the cerebellum pass down the cord by the antero-lateral and direct cerebellar tracts, and Professor SCHÄFER has informed me that a more careful examination of the spinal cords of Monkeys upon which cortical ablations had been performed has revealed numerous scattered degenerated fibres in the periphery of the antero-lateral region, so that many of these degenerated fibres below the lesion may be not simply commissural fibres but long tract fibres. If this be so, it will account for HOMÈN's results. This observer found that injury of the antero-lateral portions of the cord, together with the pyramidal tract, produced a more permanent motor defect than when the lateral tract alone was injured. It may also account for the very incomplete return

* *Loc. cit.*

† Ref. 'Neurolog. Centralblatt,' 10, 8. "Sull' origine e decorso dei peduncoli cerebellari e sui loro rapporti cogli altri centri nervosi," pel Dr. VITTORIO MARCHÉ. 'Pubblicazione del R. Inst. di Studi Superiori in Firenze.'

of movement shown by Monkey No. V., in which subsequent microscopical examination showed degeneration in both anterior columns.

Fig. 1.

FIG. 1 is a drawing made from a photograph showing the well-marked degeneration in the median, anterior, and antero-lateral regions of the spinal cord in the upper lumbar region. It clearly shows that there are as many fibres degenerating downwards as upwards in the antero-lateral region. The preparation was made from the spinal cord of Case III. Magnification, 20 diameters.

With regard to the "*recrossed*" pyramidal fibres described by PITRES,* HOMÈN,† and SHERRINGTON‡—the latter author states that he found degenerated fibres in the crossed pyramidal tract of the opposite side in Monkeys. I was unable to satisfy myself of their existence in Cases III. and VII. This, however, is due to the fact that the fibres are scattered, and the animals were allowed to live a sufficiently long time to produce a true sclerosis and disappearance in part of the degenerated fibres.

The ascending degeneration above the lesion.—The degeneration of GOLL's column in a perfect hemisection is limited to the same side, and it disappears at the post-pyramidal nucleus.

The degeneration of the postero-external column soon disappears, partly because most of the fibres are short and soon terminate in the grey matter, and partly because the long fibres run towards the mid line to ascend in GOLL's column.

The antero-lateral tract of GOWERS.—The degeneration in this tract could be traced upwards as far as the nucleus lateralis, the number of degenerated fibres rapidly diminishing in the medulla. It can be traced as far up as the lower border of the pons Varolii. As soon as the degenerated fibres appear amidst the arcuate fibres, the number rapidly decreases. (*Vide* fig. 8, Plate 4.)

* PITRES, 'Comptes Rendus,' vol. 99, 1884.

† *Loc. cit.*

‡ SHERRINGTON, "Degeneration in Spinal Cord," 'Journal of Physiology,' 1885.

TOOTH,* who performed hemisection of the spinal cord in Monkeys for the purpose of tracing the degenerations, considers that these fibres probably end in the nucleus lateralis. This observer does not state what effects as regards sensation, return of motility, &c., occurred after the operation.†

EDINGER‡ states that in Fishes, Reptiles, and Amphibians large numbers of fibres decussate from the base of the posterior horn to reach the anterior column in front of the central canal. He figures also a section of the spinal cord of a young Cat, which shows this decussation to some extent.

In the human subject, EDINGER remarks that they are very difficult to demonstrate, because they run forwards and upwards before passing over to the other side. He considers that those fibres coming from the posterior root are connected with cells of the posterior horn, and from these arise fibres which pass across by an anterior commissure to the antero-lateral tract of the opposite side.

AUERBACH§ at the instigation of Professor EDINGER, performed the following experiment. He destroyed the posterior horn, the posterior column, and the lateral column in that part where the posterior root fibres enter, for some considerable length of the cord, on one side and on both sides. Besides a sclerosis of the direct cerebellar tract there was also degeneration of the fibres in the anterior commissure. Bilateral injury produced bilateral degeneration of the anterior commissure. The number of sclerosed fibres in the antero-lateral tract diminished continually from below upwards. There are objections to the acceptance of these experiments as proving anything conclusive. I have performed a similar operation, viz., a longitudinal section of CLARKE's column, but it was impossible to avoid injury of the anterior commissure, and there was degeneration of the antero-lateral tract, but it was most marked on the same side as the degenerated direct cerebellar tract. The observation of ROSSOLYMO, quoted by EDINGER, is simply explained thus: the sclerosis of the posterior horn had directly affected many posterior root fibres. Although KÖLLIKER quotes EDINGER, and figures diagrammatically the decussation of sensory fibres going to form the antero-lateral tract, he offers no histological evidence in support thereof.

If the fibres take an upward and forward course, then hemisection in three places so as to destroy one half of the cord for half a centimetre, must cut through a considerable number of those fibres before they have decussated, and consequently we ought to see degenerated fibres in the antero-lateral of the opposite side. This I have been unable to observe, neither does TOOTH§ mention it; so that I think there is, at

* 'Degeneration of the Spinal Cord.' Gulstonian Lecture, 1890. HOWARD TOOTH.

† [At a recent meeting of the Neurological Society, TOOTH stated that his experiments agreed with mine as regards retention of sensation to pricking and heat on both sides after hemisection.—Note added, November 21, 1891.]

‡ "Einiges vom Verlauf der Gefühlsbahnen im Centralen Nervensystem," von Dr. L. EDINGER, in Frankfurt am Main. 'Deutsche Med. Wochenschrift,' 1890.

§ *Loc. cit.*

present, no conclusive evidence to show that sensory fibres decussate in the anterior commissure to form the long antero-lateral tract fibres. In a successful hemisection, I have found all the ascending degeneration on the side of the lesion only.

The sensory paths then are through the posterior roots—

1. To cells in the cord.
2. To cells in the medulla.

1. There are two long afferent or centripetal tracts in the cord which arise from cells, and pass upwards to the brain.

(*a.*) Fibres of direct cerebellar tract which arise from CLARKE'S column; it is an *uncrossed path* between the fibres of the posterior root and the cerebellum. "The fact that it degenerates upwards indicates that we are to look upon it as a centripetal conducting system. A portion of the lateral cerebellar tract is supposed not to enter the corpus restiforme, but to go on brainwards as far as the corpora quadrigemina, and then near the fillet to turn backwards, and so lying near the surface of the brachium to stream into the cerebellum."* According to BECHTEREW,† it conveys impulses in connection with localization in space, although it is possible that it may convey tactile impressions.

(*b.*) Fibres of antero-lateral.—These are considered to arise from cells of the posterior horn, and are supposed to decussate either in the anterior or posterior commissures, or both. I think it *possible* that these may arise from cells of the grey matter of the same side.

In hemisections of the cord the degeneration is limited to the same side, as far as my observations go.

2. The crossed pyramidal tract below the hemisection shows a number of healthy fibres scattered among the degenerated fibres. The direct cerebellar fibres (as seen by the course of degeneration exhibited in Plate 2, photo-micrograph 18, just above the lesion) course along the lateral border of the posterior horn, while the antero-lateral pass outwards, more especially in front of the pyramidal tract. It must be admitted that my evidence is in no way conclusive. TOOTH, who has made hemisections of the cord for the purpose of following the degenerations, killing the animals at a suitable period of time, has informed me that he has not observed any degenerated fibres in the opposite antero-lateral tract.

GOWERS,‡ who first described the tract, says on p. 122:—"In the lumbar region the tract lies across the lateral column on a level with the posterior commissure, from which its fibres probably come. Fibres probably pass to it through the whole length

* 'The Anatomy of the Central Nervous System,' OBERSTEINER and HILL.

† "Über die Erscheinungen, welche die Durchschneidung der Hinterstränge des Rückenmarkes bei Thieren herbeiführt und über die Beziehungen dieser Stränge zur Gleichgewichts-Funktion," von Prof. W. BECHTEREW; 'Archiv für Physiologie,' DU BOIS-REYMOND, 1890.

‡ 'Diseases of the Nervous System,' vol. 1, "Spinal Cord and Nerves."

of the cord, and then are mingled together, so that the degeneration from a lesion of the lower part of the cord is not dense. This tract has recently been found by BECHTEREW to undergo development at a different period from the rest of the lateral column. It is almost certainly a sensory tract, and *physiological facts* seem to show that its fibres are connected with the posterior roots of the opposite side."

GOLL's column is the other long ascending tract. Most observers are agreed that it is made up of fibres of the posterior roots which pass into the posterior column of the same side, tend towards the mid line to form the posterior median column, and do not reach their end station until they arrive at the nucleus of the funiculus gracilis of the medulla. Section of the roots of the cauda equina in Monkeys showed only degeneration of fibres of the same side—*vide* my article on " The Bipolar Cells of the Spinal Cord," 'Brain,' Part IV., 1890. TOOTH and SINGER's experiments (*loc. cit.*) support this view. It is probable that sensations passing along these fibres, having reached the nucleus in the medulla, decussate to the opposite side by the fibres of the fillet.

Most authorities consider that the fibres of GOLL's column convey sensations connected with the muscular sense.

In the 'International Journal of Medical Science,'* January, 1891, I published the report of a case of complete sclerosis of GOLL's column, and referred to three other cases ; notably an almost identical case reported by VIERORDT, in which there was no loss of sensibility to tactile, painful, or thermal sensations ; whether the muscular sense was lost or not could not be determined because of the great muscular wasting.

In locomotor ataxy in which there is loss of the muscular sense these columns are involved.

There are then four paths by which sensory impulses may be conveyed to the brain :—

1. By the posterior roots through fibres of GOLL's column of the same side to post-pyramidal nucleus, thence by fillet to the opposite side.

2. By posterior roots to short fibres of postero-external column to form sensory collaterals in contact with cells of CLARKE's column, and thence by direct cerebellar tract of the same side. Whether all the fibres of this tract go to the cerebellum, or whether some may not go to the cerebral hemisphere of the opposite side, cannot be determined.

3. By posterior root fibres, to end in collaterals around cells of posterior horn of opposite side, and thence by antero-lateral tract fibres to the medulla (GOWERS), or the fibres instead of crossing on their entrance into posterior horn come into connection with cells which give off fibres that pass by the anterior commissure to the antero-lateral tract of the opposite side (EDINGER). Neither of these theories, however, is supported upon a firm basis, nor is it known what sensory impulses are conveyed by

* "Complete Sclerosis of GOLL's Column. Chronic Leptomeningitis. Alcoholism." 'Journal of International Medical Science,' January, 1891.

the antero-lateral tract. All that seems certain is that *there is an ascending tract*, long considered to be a part of the direct cerebellar tract, but in all probability quite distinct, which tract has been traced to the upper part of the medulla, disappearing in the arciform fibres.

4. The grey matter may conduct sensory impressions of a painful character (SCHIFF).

As regards previous experiments conducted upon animals with a view of determining the paths of conduction in the spinal cord, I will refer first to those made upon Monkeys. They are limited in number, whereas the experiments upon Dogs, Rabbits, Pigs, Frogs, Pigeons, and other species of animals of a lower type than the Monkey are innumerable, and I cannot do more than allude to some of the more important work upon the subject.

Professor FERRIER* states, "When a hemisection of the cord is made, voluntary motion occurs on the side of lesion and paralysis of sensation on the opposite side.

"The following experiment which I made on a Monkey illustrates these propositions. The cord was cut on the left side between the 7th and 8th dorsal nerves, to the extent indicated in the accompanying figure, which is after a photo-micrograph of the first slice from the cord above the incision. The cord was intact except at the region of the lesion. Directly after this injury, and till death eighteen days subsequently, there was on the side of lesion absolute paralysis of motion, and perfect retention of sensibility, *not apparently heightened*, to every form of stimulation, tactile and painful. The animal's attention was immediately excited by a touch anywhere on the same side below the lesion, and it put its hand to, or rubbed the part touched or pinched. On the opposite side voluntary motion was unimpaired, and the animal was able to use its right leg freely and forcibly with perfect precision. There was, however, *absolute insensibility* to every form of sensory stimulation, such as contact, pinching of the toes and muscles, and a degree of heat which excited lively manifestations of uneasiness and pain in the left leg or in the hands. It was observed, also, that though the animal could move its right leg for volitional purposes with perfect precision when the eyes were open, it could not do so when the eyes were blindfolded, being evidently unaware of the position of its leg, and unable to extricate it from any obstruction. This, however, it readily effected when the eyes were freed.

"With the exception of certain statements made in reference to the muscular sense, which will be considered more at length subsequently, the results of this experiment agree with those obtained by BROWN-SÉQUARD, and with the facts of disease or injury of one-half of the spinal cord in Man. It has usually been found by other experimenters, and also in cases of unilateral disease of the cord, that on the side of lesion there is a hypersensitiveness to sensory impressions, but this was not apparent in the experiment above recorded. What the cause of this hyperæsthesia so frequently

* 'The Functions of the Brain,' p. 51.

observed may be, is not quite clear; but it does not appear to be an essential feature of a lesion capable of inducing total anæsthesia of the opposite side. It is probable, from the results obtained by other physiologists, that the sensory paths are not so entirely crossed in many of the lower animals *as they appear to be in the Monkey* and Man, and that the paths of voluntary motor impulse are not exclusively direct, or confined to the same side of the spinal cord."

This is so very pertinent to the subject of this paper that I have quoted in full the remarks of Professor FERRIER. It should be noticed that the photograph given by Professor FERRIER shows an incomplete hemisection, for the whole of the posterior median column on the left side is intact, likewise that portion of the anterior column situated within the anterior horn; in fact, the destruction does not seem so extensive as Case I. here recorded. The mode of preparing the section is not likely to yield such satisfactory results as embedding in celloidin and cutting a large series of sections, as I have invariably done, nor does FERRIER state what degenerations occurred above the lesion.

I made a preliminary communication to the Physiological Society, in March, 1890, and showed some animals upon which I had made hemisection of the spinal cord.

Later on, in May, 1890, I read a communication to the Neurological Society, and exhibited the sections. Professor FERRIER subsequently referred to some experiments that he had made on unilateral section of the *lateral columns* in the Monkey, and he found that sensation was retained on both sides, and from four other experiments he made he comes to the following conclusion:—

'Lancet,' 1890, p. 1416. "To my mind the evidence from the various facts mentioned is in favour of the view that the whole of the sensory paths pass up the opposite side of the spinal cord, and that they are not contained in either the posterior median columns, or in the direct cerebellar tract, or in the antero-lateral tract, and as the pyramidal tract may be entirely sclerosed without any affection of sensation we are led, by a process of exclusion, to suppose that the sensory tracts ascend in immediate relation with the central grey matter. If the sensory tracts retain constant relation with the grey matter this would account for their non-decussation upwards like the other afferent tracts of the cord."

My experiments, if they show nothing else, at any rate show that the Monkey cannot be included with the animals in which the sensory paths entirely cross. I would, however, go a step further, and say that they show: (1) that painful sensations pass up either side of the cord; (2) that sensations by which an animal localises his relation to the external objects producing sensory impressions pass chiefly up the same side; (3) that impressions leading to consciousness of position in space pass up the same side.

The proof offered in favour of (1) is that the animal, after complete hemisection, felt painful impressions, such as pricking and heat, on both sides; (2) that the animal only localized the seat of the painful impression on the non-paralyzed side; *e.g.*, when

it was pricked or touched with a test-tube containing hot water, it would scratch the part irritated, whereas it would put down its hand, but nowhere near the place, when stimulated in a like manner on the paralyzed side. With the clip test this was still more strikingly exhibited, by the instant removal from the non-paralyzed side, when the animal had no notion of its being applied, the long delay on the paralyzed side before it gave signs of feeling (sometimes never showing any sign, as in Case V.), and then the feeling being frequently referred to an identical spot on the opposite foot. This condition of Allochiria was only afforded by the clip test. We must, therefore, consider in what this test differs from the others.

(1) I noticed that Allochiria only occurred when the clip was placed upon the foot.

(2) The clip would produce not merely a painful pressure sensation, but also a tactile sensation.

Professor OBERSTEINER* associates the condition termed Allochiria especially with sclerosis of posterior columns, and I will refer now to an important paper by him on this subject.

"This disorder consists in the fact that although the sensibility is retained more or less completely, yet the patient is not clear, or is frequently, if not constantly, in error, as to which side of the body has been touched. I would term the phenomenon Sensory Allochiria, or shortly Allochiria (ἄλλος χειρ), or confusion of sides. When we test the sensibility of a patient, on the leg for example, and find that the two points of the æsthesiometer are recognised as such at a moderate distance apart, or when a prick or pressure is fairly localized, and yet (as frequently occurs) the irritation is referred to the other side, we have the condition before us. The power of localization is retained as to details, while doubt or error exists as to the side touched, the irritation being commonly referred to the corresponding part of the other side. I believe the phenomenon is less rare than overlooked, as errors on the part of the patient are apt to be regarded as merely a *lapsus verbi.* In the case of intelligent patients, however, and with care, it soon becomes apparent that this is not the true explanation."

Professor OBERSTEINER then gives four cases in which this phenomenon occurred; the symptoms pointed to sclerosis of the posterior columns, and in one case this was verified by an autopsy.

"Experience shows that the sensory and motor relations of the two sides of the body are not so independent of each other as is sometimes supposed. We meet rather with phenomena which indicate a close relation between symmetrical regions on both sides. As regards the motor association may be mentioned the well-known phenomenon of associated movements, particularly in paralyzed limbs." †

* "On Allochiria: a Peculiar Sensory Disorder." By H. OBERSTEINER, Professor in the University of Vienna. 'Brain,' vol. 4, p. 153.

† [August 10th, 1891.—Dr. GOWERS has kindly furnished me with a list of other important papers on

The accompanying diagrams explain the condition of Allochiria as observed in the animals experimented upon by me.

Diagram I.

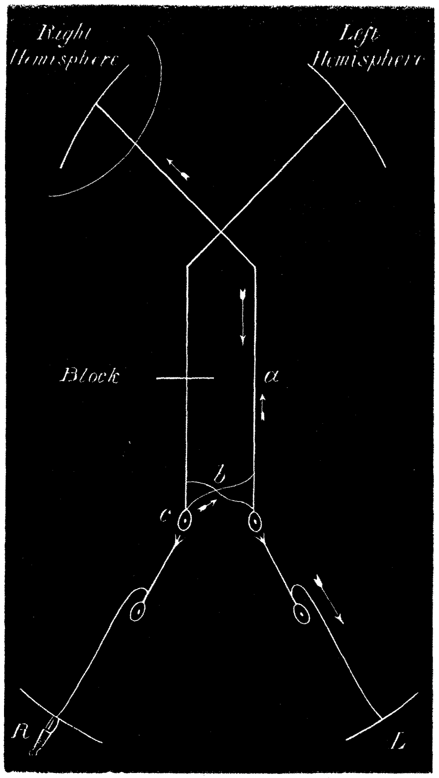
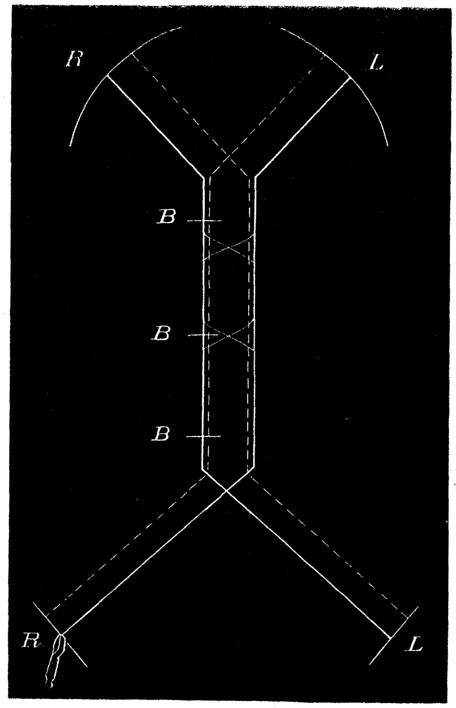


Diagram II.



Hemisection made in the dorsal or cervical regions at B on the right side.

The animal would be unable to feel the clip on the left foot, and there would be no desire to remove it.

When fixed on the right foot the impulses would pass up to the left hemisphere, and there would be no false projection outwards to the other foot, unless it be argued that, owing to the block in the motor path from the left hemisphere, the animal is unconscious of the existence of his leg, which is of course untenable.

The clip is fixed on the sole of the right foot which is paralyzed by the hemisection of the right side of the cord. The impulses which travel up the posterior roots, and posterior columns of same side, arrive at the cell (*c*); the channel of least resistance is by the nerve process which this cell gives off to the hemisphere of the *opposite* side, but owing to the block, the impulse passes by a connection *b* to the opposite side, by which connection it reaches the hemisphere of the *same* side. Sensory impressions received in the right hemisphere are referred to impressions coming from the left

the subject of Allochiria: 'London Med. Record,' 1883, p. 438; Dr. ARM. HUBER, in Zürich, 'Münch. Med. Woch,' 1888, No. 34, p. 563, No. 35, p. 585; GELLÉ, 'Gaz. des Hôp.,' 1888, No. 11; GELLÉ, 'Le Progrès Médical,' 1888, 6, 7, 8.]

foot. Consequently, the animal projects the sensation received from the right foot to the left foot, and it believes the cause of irritation is there, until undeceived by repeated fruitless endeavours at removal, and by visual correction. Whether this explanation be the correct one or not, it seems to me to support the view that the path of least resistance for some sensory impressions, *e.g.*, tactile and muscular, passes up the same side of the cord, and inasmuch as the same phenomenon of Allochiria was observed in the high hemisection of the 3rd cervical segment as in the mid dorsal, upper dorsal, or lower dorsal regions, we must conclude that the main decussation does not take place till above the 3rd cervical.

If we assume, as in Diagram II., that all sensory impulses coming from the foot decussate in the spinal cord, then we are unable to explain the result of this clip test.

When the animals have recovered motility in the paralyzed limb, as a rule the Allochiria has passed away.* In the case where, after complete return of sensibility and almost perfect motility, the leg area was removed from the same side as the cord lesion, we saw that there was complete paralysis and greatly diminished sensibility in the previously sound leg, the animal taking no notice of the clip when placed upon the left side of the foot, but immediately removing it from the right. The disappearance of the Allochiria was probably due to the establishment of collateral channels other than the corpus callosum, by which sensory impressions are conveyed to the left hemisphere. Many very able experimenters—notably MUNK, SCHIFF, LUCIANI, and more recently HORSLEY—among psychologists, BASTIAN and JAMES—consider that the motor areas of the cortex cerebri are sensory, while FERRIER and others are of an opposite opinion. I cannot here enter into the arguments for or against. Mr. HORSLEY has told me that, after removal of portions of the cortex cerebri for disease, he has observed a sensory paralysis result on the opposite side. In connection with this I will quote EDINGER,† p. 60 :—

"Sensation may also suffer from affection of the cortex of the brain. The most commonly observed symptoms are feelings of numbness, heaviness, and marked disturbance of the muscle-sense. The sense of touch is as a rule dull, so far as the judgment of the patient is concerned, but very slight sensory irritations may still be felt if they are of a simple character (such as touching with a feather, point of a needle, &c.). We do not know of any particular part of the cortex, disease of which especially leads to disturbance of sensation."

A case to the point recently occurred in Charing Cross Hospital. A young woman

* [December 3, 1891.—Professor SCHÄFER has informed me that he has lately made a hemisection of the dorsal spinal cord in a Monkey for the purpose of studying the resulting degenerations. His observations entirely agree with mine as regards sensory conduction. When the animal had recovered associated movements, he removed the leg area on the opposite side; this brought back the paralysis. Unfortunately he did not test the sensibility. I asked him to do this experiment as a complementary one to that described.]

† EDINGER, "Structure of the Central Nervous System." Translation by VITTEM and RIGGS, 1890.

affected with left-sided hemiplegia from thrombosis of vessels in the right hemisphere suffered also with numbness and loss of power of localization on the left side. A small clip fixed on the left toe was considered by the patient to be a slight prick with a blunt needle upon the ankle; but, although it was a strong clip, it did not cause any marked inconvenience, nor did she cry out to take it off. When placed upon a similar spot on the right side, she immediately cried out something was pinching her, and she exactly localized the spot where the clip was fixed. She stated that she felt much better upon that side. The patient did not see in either case what I was doing when I applied the clip. Of course the gyrus fornicatus, or its fibres, may have been injured, and this might explain the diminished sensibility. Professors HORSLEY and SCHÄFER have shown that removal of the gyrus fornicatus produces anæsthesia of the opposite side of the body.* Perhaps this may account for the loss of sensibility in the opposite side after removal of the leg area, viz., the case of the Monkey recently referred to. It may have happened that the gyrus fornicatus was partially destroyed in the ablation of the leg area.† This does not, however, affect the argument that I have brought forward in respect to the causation of Allochiria.

My experiments seem to prove that, in the Monkey, *painful sensations and sensations of heat can pass up either side of the cord*, and they agree with the results of experiments upon the Dog obtained by WEISS, OSAWA, and HOMÈN.

But experiments do not show which is *the path of least resistance* for such sensations when coming from one side of the body, whether it is the same side of the cord or the opposite. They do, however, show conclusively that *all* sensory impulses, at least in the Monkey, do not decussate over to the other side for a long distance, if at all, in the spinal cord.

Painful sensations one would expect to have far less definite localization in their course than tactile sensations have, and it may be that lateral branches allow of sensory transmission from one side of the body by either side of the cord. Except in two cases in which there was hyperæsthesia present on the side of the lesion, there was delay in the signs of feeling after application of the stimulus on the paralyzed side.

The ready way in which the animal would scratch the part pricked on the non-paralyzed limb, while it would put its hand down, but grope about nowhere near the limb on the paralyzed side, shows to my mind conclusively that its localization in space is in no way impaired on the non-paralyzed side, while it is on the paralyzed.

Again the way in which the animal would by a purposive coordinate movement

* 'Phil. Trans.,' vol. 179 (1888), B., pp. 1-45.

† [December 11, 1891.—A case has been described lately of "Traumatic Hæmorrhage from a Vein of the Pia Mater; Compression of BROCA'S convolution and of the Sensori-Motor Area of the Cortex Aphasia; Partial right Hemiplegia and Hemianæsthesia; Trephining; Removal of Clot; Recovery.' By M. ALLEN STARR, M.D., Ph.D. and CHAS. MCBURNEY, M.D. 'Brain,' Parts LIV. and LV., 1891 This case most clearly shows the existence of *tactile sensory functions in the cortex of the motor area independently of the gyrus fornicatus*.]

draw up the non-paralyzed leg, and oftentimes without looking remove the clip, is a proof that in these cases the muscular sense was not lost in that limb; we should therefore expect *à priori* that it was impaired or lost in the other, but the paralysis would prevent us finding out.

I shall now consider the evidence afforded by experiments upon other animals, and also the clinical and pathological evidence afforded by disease and injury of the spinal cord in Man.

Before doing so I would point out that these experiments, which I have made upon Monkeys, are more valuable than like experiments made upon other animals, for the following reasons :—

(1.) The structure of the nervous system in the Monkey approaches much more closely that of Man than Rabbits, Dogs, Cats, &c.

(2.) Monkeys have, by the tests I have applied, shown much more conscious manifestations of feeling, by the use of the hand in the removal of the cause of irritation, than other animals of a lower type are able to do.

(3.) These experiments have been made with strict antiseptic precautions, and the wound has always healed by first intention. The line of incision in the cord (if the animal has been allowed to live a sufficiently long time) has been filled up by fibrous tissue. I have not mentioned the fact previously, but I now take the opportunity of stating that *I have not found new nerve fibres at the seat of lesion*, thus agreeing with SCHIEFFERDECKER,* GOLTZ† and FREUSBERG, and HOMÈN,‡ and opposing the results of NAUYN and EICHORST.

The literature relating to experiments upon animals of a lower zoological type than the Monkey is enormous. Dogs, Cats, Pigeons, Pigs, Guinea Pigs, Frogs, and Rabbits have been used for experiments, and a variety of lesions have been produced with a view of determining the paths of conduction.

A concise and able summary of the results of these experiments is given by KÖBNER in his article on "Unilateral Lesions of the Spinal Cord" ('Deutsch. Archiv für Klin. Med.,' 1877), and also by ECKHARD in his most admirable article, "Rückenmark und Gehirn," chap. 5, "Das Cerebrospinalorgan als Leitungsorgan" ('Handbuch der Physiologie,' HERMANN, vol. 2). In most cases, for the older literature of the subject, I have contented myself with referring to these two articles; but for some of the more important experimental work I have referred to the original monographs, *e.g.*, those of BROWN-SÉQUARD, STILLING, VON BEZOLD, and WOROSCHILOFF. Since the two articles above mentioned were written, there have been some important papers which I shall refer to.

* "Ueber Regeneration, Degeneration, und Architectur des Rückenmarkes" (VIRCHOW'S 'Archiv,' vol. 67, 1876).

† FAGGE, 'Principles and Practice of Medicine,' vol. 1, p. 418. Edited by PYE SMITH.

‡ *Loc. cit.*

HIPPOCRATES, CELSUS, and ARETÆUS knew of the occurrence of paralysis of sensation and voluntary motion, after injury to the spinal cord, below the injured part.

GALEN was the first to make experiments. He operated on young Pigs, and found disappearance of function on the side of the lesion. (According to BROWN-SÉQUARD these experiments relate to motion only.)

FODÉRA,* however, was the first to investigate the influence of injury on one side of the cord with regard to sensation, and afterwards CALMEIL† showed that sensation and motion are not exclusively confined to certain white columns of the cord; their experiments even seemed to prove that the greater part of the sensory fibres of one side ascend to the brain through the other side. In Germany SCHOEPS‡ pointed out the importance of the grey matter.

VAN DEEN§ disproved the view of a functional separation of the anterior and posterior halves of the spinal cord, and his experiments were more or less confirmed by EIGENBRODT,|| KÖLLIKER and others.

STILLING¶ contradicted the distinction of a right and left half; according to him sensibility continued to exist on both sides after hemisection.

GALEN, FLOURENS, F. NASSE, LONGET, KÜRSCHNER, VOLKMANN, and CHAUVEAU did not believe in any decussation either motor or sensory.

BUDGE considered the motor as not decussating, and the sensory fibres as partly crossing.

VAN DEEN was of opinion that the motor fibres do not decussate, but that sensation has two paths of conduction in the cord.

According to STILLING motor and sensory conduction takes place on both sides at the same time, and in a uniform manner, so that if conduction is interrupted on one side, the other side takes on the whole of the function.

BROWN-SÉQUARD lastly held the view that the conduction of voluntary motion is direct, that of sensation completely decussating.

As BROWN-SÉQUARD'S** views are generally accepted, and his experiments are held to be conclusive proof of the complete decussation of the sensory paths of the cord, with the exception of those fibres which convey muscular sense impressions (these BROWN-SÉQUARD believes pass up the same side), we shall, therefore, quote them fully.

BROWN-SÉQUARD states: " We will try to prove that the conductors of sensitive impressions make their decussation in the neighbourhood of the place of insertion of

* MAJENDIE 'Journal de Physiologie,' 1823.

† 'De Loco Affect.,' lib. 2, cap. 7; 'De Admin Anat.,' lib. 8, cap. 6, 8, 9.

‡ SCHOEPS, MECKEL'S 'Archiv,' 1827.

§ VAN DEEN, 'Traités et Decouvertes, &c.,' Leyden, 1841.

|| EIGENBRODT, 'Leitungsgesetze im Rückenmark,' Giessen, 1849.

¶ STILLING, 'Untersuchungen.'

** 'Courses of Lectures on the Physiology and Pathology of the Central Nervous System.' By C. E. BROWN-SÉQUARD, M.D., F.R.S.; p. 30.

the sensitive nerves, or roots of nerves, in the cerebro-spinal axis. As regards the sensitive fibres of the trunk and limbs, we will try to show that their decussation takes place in the spinal cord. The following experiments seem to be decisive in this respect:—

"(1) The spinal cord of a Mammal is laid bare at the level of the two or three last dorsal vertebræ, and a lateral half of this organ (including the posterior, the lateral, and the anterior column, and all the grey matter on one side) is divided transversely. The animal is left at rest for a little while, and then it is ascertained that sensibility seems to be much increased in the posterior limb on the side of the section, while it seems to be lost or extremely diminished in the posterior limb on the opposite side. There seems to be, therefore, *hyperæsthesia* behind and *on the side* of a transversal section of a complete lateral half of the spinal cord; while, on the contrary, there seems to be *anæsthesia* behind the section and on the opposite side.

"This experiment is one of the two made by GALEN; but he seems not to have looked at all at the condition of sensibility, and he simply states that there is a paralysis on the side of the section, and no paralysis on the opposite side.

"Sir ASTLEY COOPER, under the suggestion of Dr. YELLOWLY, has made a similar experiment, except that the section was higher; the state of sensibility is not mentioned, and, as regards movement, there was paralysis on the side operated upon.

"SCHOEPS, VAN DEEN, and STILLING have observed that sensibility is not lost in the limb or limbs behind, and on the side of the section of the lateral half of the spinal cord; but they have not remarked the most important fact, that on the opposite side there is anæsthesia. They also do not mention this curious result of this experiment, the existence of hyperæsthesia on the side of the injury.

[May not this have been because these observers did not find any facts to warrant the inference of hyperæsthesia on the same side, and anæsthesia of the opposite?—F. W. M.]

"FODÉRA was very near discovering that there is a decussation of the sensitive fibres in the spinal cord. He says he has found, in some cases, that a section of one of the posterior columns caused a diminution of sensibility in the opposite side of the body; but that in other cases he has seen the reverse. He also has sometimes remarked that the section of one of the posterior columns causes hyperæsthesia on the same side, and that a section of these two columns produces hyperæsthesia on the two sides, but he declares, also, that he has seen the reverse. (See his paper in MAJENDIE's 'Journal de Physiologie,' vol. 3, pp. 191–217.)

"Two explanations for some of the results of a section of a lateral half of the spinal cord may be proposed as regards sensibility. Either it may be imagined, as it has been by several German physiologists, that the grey matter has the power of transmitting sensitive impressions in such a manner, that one lateral half of this substance is sufficient for the two sides of the body, or that the conductors of sensitive impressions decussate in the spinal cord, so that those which come from the left side of the body

pass into the right side of the spinal cord, and *vice versâ*. The hypothesis of the Germans may explain the fact that sensibility persists on the side of the section, but it is proved to be absolutely inadmissible, by the fact that there is anæsthesia on the opposite side. We will see that the other experiments we have to mention are also in opposition to the views of the Germans (STILLING, SCHIFF, and others). On the contrary, all the facts concur to prove the existence of a decussation.

"(2) If, after having made a first section of a lateral half of the spinal cord in the dorsal region, on the right side, for instance (*see* fig. 9, *s*), and after having ascertained that the right posterior limb is hyperæsthetic, or at least extremely sensitive, we divide the left lateral half of the spinal cord in the cervical region, we find then that the *right* posterior limb loses entirely, or almost entirely, its sensibility. This experiment shows clearly that the sensitive impressions coming from the *right* posterior limb, after the first section, passed across the spinal cord from the right into the left side, along which they were transmitted to the encephalon.

"(3) To obtain a very striking result from the experiment which consists in only one section of a lateral half of the spinal cord, it is better to make it after the posterior columns have been divided. We know that after this there is hyperæsthesia in the parts of the body which are behind the section; if, after having ascertained this fact, the section of a lateral half is completed when the posterior columns have been divided, we find that the hyperæsthesia seems to increase on the side of the second operation, while on the opposite side, not only the hyperæsthesia, but sensibility entirely disappears.

"(4) The spinal cord is laid bare in the lumbar region, and a careful division of the entire extent of the part of the organ giving origin to the nerves of the posterior limbs is made so as to separate the two lateral halves of the organ, one from the other. The result is: Voluntary movements still exist in the posterior limbs (though diminished on account of the injury to the muscles of the lumbar region), but sensibility is entirely lost in them.*

"(5) A longitudinal section is made in the cervico-brachial enlargement of the spinal cord, so as to separate it in two lateral halves. I ascertain then that sensibility is lost in the two anterior limbs, while it remains, and even seems to be increased, in the two posterior limbs.

"As far as experiments go, it is very difficult to decide whether the decussation of the conductors of sensitive impressions is absolutely complete or not, but it seems to be very nearly, if not absolutely, complete. We shall see, by and by, that pathological cases seem to show that in Man the decussation is complete."

* [On the contrary, compare VULPIAN ('Dictionnaire Encyclopédique des Sciences Médicales,' vol. 8, p. 384) who says: "Il est très présumable que la division longitudinale de la région lombaire de la moelle en deux moitiés latérales, lorsqu'il n'y a aucune complication, et que l'opération est faite exactement sur la ligne médiane, ne détruit la sensibilité ni dans l'un ni dans l'autre des deux membres postérieurs."—F. W. M.—Aug. 10, 1891.]

On p. 41, *loc. cit.*, BROWN-SÉQUARD states: "We will then try to show the disagreement between these results and a theory recently proposed by M. MORITZ SCHIFF,* according to which the posterior columns of the spinal cord are the channels for tactile impressions, and the grey matter the conductor of painful impressions."

"We will now say a few words on the decussation of the conductors of tactile impressions. If a latent half of the spinal cord has been divided transversely in the dorsal region, we find that when we touch the sole of the foot of the posterior limb on the side operated upon, the animal raises its head and tries to look at the place irritated (in which attempt it cannot succeed, as its eyes are covered). On the opposite side, the touching of the skin of the toes does not produce the least effect. It seems, therefore, that *the conductors of the tactile impressions decussate in the spinal cord* as well as those of painful impressions, so that the right side of this organ transmits to the sensorium the impressions which come from the left side of the body, and *vice versâ*."

[As I have previously remarked, there is considerable evidence in favour of SCHIFF'S views, with regard to tactile sensation, and when the pathological cases are referred to, we shall see that cases have occurred which support them.—F. W. M.].

M. BROWN-SÉQUARD, in a footnote on p. 42, states:

"I must say that it is absolutely impossible to know, *while* we make a section of part of the spinal cord, what is the precise depth of the injury; it is mere guess work," and he adds, it is necessary to remove the spinal cord and harden it in alcohol. I would add that it is also necessary to cut microscopical sections of the lesion, and the spinal cord above and below, and to note the degeneration.

With regard to the production of *hyperæsthesia*, M. BROWN-SÉQUARD made a number of experiments tending to show—

1. Hyperæsthesia in all parts of the body behind deep injuries to the posterior column of the spinal cord.

2. After transverse incision of the restiform bodies, the cerebellum, the processus cerebelli ad testes, and in the tubercula quadrigemina.

3. After a section of either the anterior or the lateral columns.

4. Hyperæsthesia greater after a section of the posterior columns and the posterior horns of grey matter and the neighbouring parts of the lateral columns and central grey matter than after a section of any other part of the cord.

M. BROWN-SÉQUARD does not refer in these lectures to some curious phenomena he discovered after unilateral section of roots of spinal nerves in the lower dorsal and upper lumbar region; as they seem to be of importance in the explanation of hyperæsthesia, I will briefly relate what M. BROWN-SÉQUARD states in a paper entitled "Recherches Expérimentales sur les Voies de Transmission des Impressions Sensitives

* 'Untersuchungen zur Naturlehre des Menschen und der Thiere.' Von J. MOLESCHOTT; vol. 4, pp. 84–87, 1858.

et sur des Phénomènes singuliers qui succèdent à la Section des Racines des Nerfs Spinaux. Communiquées à la Société de Biologie en Juillet, Août, et Septembre 1855."

There are five experiments described, but I will refer to Experiment I., Part III.

"If all the roots of the five or six last dorsal nerves, and of the two first lumbar nerves of the right side are cut in a Guinea Pig, a Rabbit, or a Dog, and the animal be left some minutes or hours, we find that voluntary movement is diminished in a marked manner in the right hind limb, and that sensibility is exaggerated there, whilst, on the contrary, it is diminished in a most marked manner on the opposite left limb. Besides, we find that there is vaso-dilatation in almost all parts of the body behind and on the side of section of the roots; at the same time the temperature of these parts is a little elevated (1–3 degrees) as compared with the corresponding parts on the other side. All these results are the same as those I have found occurring after section of a lateral half of the spinal cord in the dorsal region.

"Immediately after the section of the roots, the phenomena that I have indicated are extremely marked, so much so that sometimes the paralysis of voluntary movement seems complete, but after some hours less, and when even the animal survives the operation many days, or many weeks, there always remains a manifest feebleness and an incontestable hyperæsthesia in the posterior limb of the side of section of the roots, with a diminution of sensibility in the posterior limb of the opposite side."

M. BROWN-SÉQUARD then gives an account of a Dog in which this operation had been performed. I will quote his own words :—

"Sur un chien ayant subi à peu près la même opération que dans l'expérience ci-dessus, le membre postérieur droit (côté de la section), après avoir été presque complètement paralysé pendant quelques jours, a recouvré graduellement les mouvements volontaires jusqu'au degré normal ou à bien peu près, dans l'espace de cinq mois. L'hyperesthésie a persisté dans ce membre à un degré très marqué, et la sensibilité a paru être moindre qu'à l'état normal, dans le membre postérieur gauche, même au bout des cinq mois. L'examen des racines coupées a fait voir qu'il y avait eu réunion, et au milieu de fibres altérées profondément M. AUGUSTE WALLER et moi avons vu nombre de fibres régénérées. Les premiers filets nerveux qui se rendent de la moelle épinière aux membres postérieurs, chez les animaux que nous employons ordinairement pour nos recherches sur la moelle et sur les nerfs, viennent de la cinquième ou de la sixième paire lombaire."

By this experiment we know that BROWN-SÉQUARD divided the vaso-motor nerves of the part of the body behind the section. REISSNER* showed throughout the thoracic region in Man the anterior roots possessed numbers of fine nerve fibres.

* REISSNER, "Ueber die Wurzeln des Rückenmarkes des Menschen;" DU BOIS-REYMOND'S 'Archiv,' 1862.

CLAUDE BERNARD* and OSTROUMOFF,† by experiments on animals, showed the existence of vaso-motor fibres in these roots, and GASKELL‡ showed that these fine fibres existed in the anterior roots of the thoracic region in the Dog, and to him is due the merit of the association and correct interpretation of these two facts.

ROSE BRADFORD and BAYLISS,§ following up the work of CLAUDE BERNARD and OSTROUMOFF, have shown that stimulation of *certain* of these roots leads to vaso-constriction of the vessels of the limbs, and a general rise of blood-pressure. They have proved that the vaso-motor nerves to the hind limb of the Dog pass out by the 11th, 12th, 13th dorsal, and 1st lumbar roots. By cutting the mixed nerves beyond the ganglion the vaso-constrictor influence is removed, and vaso-dilatation ensues. BROWN-SÉQUARD notes this, and also the rise of temperature. I have no doubt that this produces a hyperexcitability of the nerves, for we know that one of the best ways of relieving pain is the application of cold, and such conditions as favour the flow of blood back from a part which is swollen and painful.

MARTINOTTI‖ remarks :—FODÉRA'S¶ observation that section of the posterior half of the spinal cord gave rise to hyperæsthesia in parts situated below the injury, was rediscovered simultaneously by BROWN-SÉQUARD** and L. TÜRCK.†† Both observers say that, after cutting through the lateral column, the half of the body situated behind the section is hypersensitive, and this in proportion to the extent of division of the lateral column. BROWN-SÉQUARD added, that after the hemisection, the opposite side belonging to the uninjured half of the spinal cord was anæsthetic. TÜRCK invented an approved method for testing the sensibility in the Frog, and was enabled to show that after bilateral injury of the cord, bilateral hyperæsthesia occurred. WOROSCHILOFF showed that large portions of the lateral column in the lower dorsal and lumbar regions of the spinal cord could be cut through without causing hyperæsthesia in the Rabbit, and he concluded from his experiment that hyperæsthesia resulted when the white matter, which is bounded on the inside by the grey matter, and outside by a line which unites the furthest projecting points of the anterior and posterior horns, is injured.

MARTINOTTI then describes his own experiments, which are a modification of WOROSCHILOFF'S.

He used Rabbits; limited injuries were effected in the cervical region of the spinal cord. These injuries are shown in photographs.

* CLAUDE BERNARD; BROWN-SÉQUARD'S 'Journal de Physiologie,' 1862, p. 383.

† OSTROUMOFF, PFLÜGER'S 'Archiv,' vol. 12.

‡ GASKELL, 'Journal of Physiology,' vol. 7, 1887.

§ 'ARRIS and GALE Lectures, College of Surgeons,' 1891 (not yet published).

‖ "Hyperæsthesie nach Verletzung des Halsmarkes," von Dr. C. MARTINOTTI. 'Archiv für Anatomie und Physiol., Physiolog. Abtheilung,' Supplem.-Band, 1890.

¶ *Loc. cit.*

** 'Comptes Rendus,' 1850. "Experimental Researches on the Spinal Cord," Richmond, 1855.

†† 'Zeitschrift der Gesellschaft der Wiener Aerzte,' 1850.

The animals were tested as follows:—They were first set upon a broad bench straddle-ways, and held there by a broad girth. The pressure of the hand of the observer, and the breaking of an induction current, served as a means of stimulus. The effect was estimated by the movements of the animal and its cry. These experiments agree with those of WOROSCHILOFF upon the area which, if injured, produces hyperæsthesia of the same side. But this area is not limited to the middle third of the lateral column; it reaches to the posterior third of the same. MARTINOTTI remarks that this may be due to the different region of the cord in which he performed his experiments.

In many of my Monkeys the photographs show that all this region of the spinal cord was divided, and yet there was no evidence of hyperæsthesia on the side of section, nor did I find that the animal took the slightest notice when the sole of the foot was pinched by the clip, providing it did not see it done. In two cases there was, however, decided hyperæsthesia to pricking. *Post mortem*, I found the two surfaces of the cord gaping at the point of section in one instance.

The views of SCHIFF are thus ably summarised by Professor M. FOSTER, in the 3rd edition of his 'Text-Book of Physiology':—

"SCHIFF states that when, in any part of the cord, the posterior columns only are left, all the rest of the white and grey matter being removed, tactile sensations remain though no pain is felt; there is analgesia, but not anæsthesia; a Rabbit thus operated on is readily awakened for a moment from sleep (artificially induced by bleeding), when the hind limbs, or part below the seat of injury, are even lightly touched, but exhibits no sign of pain when the nerves are laid bare and pinched, or when needles are driven through the skin.* This experiment, however, on which SCHIFF rests his theory of analgesia, does not prove the existence of tactile sensations; it simply shows that a peculiar condition may be brought about, in which a sensory impulse produces a maximum initial result, and then ceases to have any effect. The animal moved at every fresh stimulus, whether slight or strong, whether applied to the skin or a bare nerve; but after the first explosion the central organs concerned in the matter, whatever they were, appear to be exhausted. The condition is certainly a remarkable one, and may bear many interpretations."

Professor FOSTER states: "To make these views logically complete, we must suppose that, after section of a lateral half of the spinal cord, tactile sensations and voluntary movements would be entirely lost on the same side below the seat of injury, but that pain would still be felt, and the parts would still be capable of being thrown into movements by reflex action."

MIESCHER† endeavoured to ascertain the path of afferent sensory impulses in the cord by a new method. "He found that the afferent impulses which, starting from the

* 'Lehrbuch,' p. 251.

† FOSTER, 'Text-Book of Physiology,' 3rd edition, p. 551. Summary from the paper in LUDWIG'S 'Arbeiten,' 1870, p. 172.

sciatic nerve and travelling up to the medullary vaso-motor centre, caused a rise in blood-pressure by acting on that centre, passed almost exclusively by the lateral columns. When one lateral column was divided, stimulation of either sciatic produced much less than the normal effect; when both columns were divided, no effect at all was produced. When only the lateral columns were left, the other parts being destroyed, the vaso-motor influences of the sciatic stimulation appeared to be quite normal. From which it would appear that afferent impulses, such as affect the vaso-motor centre, pass from one sciatic up both lateral columns; and MIESCHER came to the conclusion that they passed more on the opposite than the same side. He also thought that impulses coming from more distant parts travelled more to the outside of the columns than those from the nearer parts." These experiments have only a value in showing that afferent impulses affecting the vaso-motor centre in the medulla pass upwards in both lateral columns, but more especially on the opposite side to the nerve stimulated.

HORSLEY and GOTCH's experiments, by another method to be referred to later on, give exactly opposite results with regard to the side upon which afferent impulses travel up the spinal cord.

WOROSCHILOFF,* however, has repeated MIESCHER's experiments, using the ordinary signs of sensation instead of blood-pressure; and has come to the conclusion that both the afferent impulses, which, starting in the hind leg, give rise, either by developing into sensations or by originating reflex actions, to movements in the head and fore limbs, and the efferent impulses, which, starting in the brain or upper part of the spinal cord, either by volition or as a result of stimulation, produce movements in the hind limbs, pass also exclusively through the lateral columns.

FERRIER† thus summarizes the work of WOROSCHILOFF:—

"The careful and varied experiments of LUDWIG and WOROSCHILOFF have shown that motor impulses may be transmitted downwards, and sensory impulses conveyed upwards, without any apparent disturbance of the normal order, when the whole of the anterior and posterior columns, and also the grey matter, have been severed, and when, therefore, only the lateral columns of the cord remain intact.

"By diverse sections of one or both lateral columns, or parts of them, they found that, when only one lateral column remained, movements of the arms and anterior part of the body could be readily excited by irritation of the opposite leg behind the section, but only with difficulty by irritation of the leg on the same side. In order that impressions on the opposite leg should readily call forth movements in the anterior parts of the body, it was found that that portion of the lateral column should remain intact which lies in the area bounded by the prolongation outwards of the

* LUDWIG's 'Arbeiten,' 1874, p. 99, or 'Leipzig Math.-phys. Berichte,' 1874, p. 248. "Der Verlauf der motorischen und sensiblen Bahnen durch das Lendenmark des Kaninchens."

† *Loc. cit.*

anterior and posterior commissures—the middle third. Slight movements could, however, be excited in the anterior part of the body if only the anterior or posterior third of the lateral column remained.

"In respect to motor impulses, their experiments showed that by sensory stimulation of parts above the lesion—the ears, etc.—movements could be excited only in the leg on the side of which at least a portion of the lateral column remained intact. If the lateral column were entirely destroyed on one side, no reflex movements whatever occurred in the leg of that side by sensory stimulation above the lesion. For the conveyance of reflex motor impulses to the leg of the same side at least the anterior half of the lateral column must remain intact. The co-ordinated movements of the leg, such as are required for sitting, springing, etc., require the integrity of the middle third of the lateral column.

"Electrical irritation of the cut surface of the cord, severed below the calamus scriptorius, was able to excite co-ordinated movements of the leg only on one side on which the middle third of the lateral column was uninjured. But tetanic contraction of the muscles of the other leg could also be induced, though the lateral column on this side was entirely severed.

"It thus appears that the sensory impulses which excite movements in parts above the section are conveyed mainly in the opposite lateral column, and specially in the middle third of this column; and that the centrifugal impulses which excite such movements as are characteristic of purposive co-ordination are conveyed in the lateral column of the same side, and specially in the middle third of this column. The relative facility with which sensory impressions on the leg of the side of lesion evoke movements in the anterior part of the body is termed by LUDWIG and WOROSCHILOFF cross hyperæsthesia; and they give a hypothetical explanation of this by assuming that on the 'side of the lesion certain inhibitory fibres have been divided.'"

WEISS* believes, from his experiment, that BROWN-SÉQUARD'S views could not be correct.

The animals used for his experiments were Dogs, and they were kept alive as long as possible after the operation in order to distinguish temporary from permanent derangement.

Eighteen young Dogs were used. All precautions were taken to make a perfect hemisection at junction of last dorsal with lumbar spinal cord.

1. Immediately after narcosis had passed off, WEISS observed loss of motility and sensibility on both sides, *and never* any of those phenomena which BROWN-SÉQUARD and others had observed after hemisection of the spinal cord.

2. One or two days after the operation, *motility* of the side opposite the lesion was more or less unimpaired, whilst the leg on the side of the injury was completely paralyzed, so that if the animal moved, the leg was extended at the hip and knee-joints and also adducted, so that it was dragged along on the floor when the animal

* Vienna 'Sitzber.,' *ut supra*

moved. *Sensibility* of the lower extremities was tested by pinching, pressure, and faradic current, *and was found to be equal on the two sides*, but slightly impaired as compared with that of the anterior extremity. In no case did he find hyperæsthesia in the paralyzed leg, upon which BROWN-SÉQUARD laid special stress as a typical phenomenon when the cord in animals was hemisected.

In a few days after the operation there was no change in the symptoms mentioned above, but at the end of the first, second, or third week a change of motility in the legs was found. In cases in which the operation had been successfully performed, a return of *associated movements* in the paralyzed leg occurred. In some cases the return of movement was so complete that after three or four weeks it was difficult to discover which of the two lower extremities was the more moveable one, because the previously paralyzed leg moved quite normally in walking and running; but when the animal was hunted round the room it would, however, occasionally fall towards the paralyzed side.

In respect to sensibility and reflex excitability, there was no change. Some animals did not recover motility in the paralyzed leg until after some weeks, and in these the *post mortem* revealed a myelitis.

When the animal could not recover any further motility, he curarized it and tested the sensibility in the lower extremities, by observing the increase of blood-pressure occasioned by stimulation of the sciatic nerve, and motility of the legs was tested by excitation of the cervical spinal cord. These experiments always gave results analogous to those observed during life. The spinal cords were hardened in the membranes, and if macroscopical examination did not suffice to show the extent of the lesion, microscopical examination was made.

Sensibility and motility were restored after 2–4 weeks. WEISS does not believe this to be due to a healing process, for he states that there was no repair of the connections of the injured tracts, as the cut surfaces were so distinctly apart that there could not be the slightest doubt about the interruption of the longitudinal conducting tracts in one half of the cord. WEISS concludes that the lateral column contains motor and sensory fibres for both halves of the body.

It might be added that the distribution of the sensory tracts may possibly be a uniform one, for the animal reacted to stimulation of each hind foot about equally.

He accepts STRICKER'S views as regards "collateral innervation" to explain the return of motility.

Besides the double hemisection already alluded to, WEISS gives the details of another experiment in which a section of the spinal cord at the junction of the lumbar and dorsal regions was made, the part of the cord remaining intact being limited to one antero-lateral column; sensibility was retained in both hind limbs.

Further experiments of his seem to show that the grey matter does not conduct any distance motor or sensory impulses.

Three successive sections were made at some little distances apart. The upper

section divided the posterior columns, the next the left lateral column, and below this the right lateral column. There was no trace of motility or sensibility on the third day.

The liability to severe myelitis, I should think, would probably interfere seriously with accepting the results of this experiment as at all conclusive, especially as WEISS did not use antiseptic precautions. (He speaks of the wounds suppurating.)

WEISS agrees, therefore, with WOROSCHILOFF in assuming that the only tracts for the conduction of sensation and of movements, which have been proved to exist, lie in the lateral column, and also that the anterior columns are incapable of conducting voluntary impulses. He also disagrees with SCHIFF in reference to conduction in the grey matter. His experiments (he believes) show that the grey matter is incapable of conducting any distance. The results obtained by HOMÈN,* with regard to the sensibility existing in parts behind the hemisection, agree with those of WEISS.† OSAWA considered that there was more diminution on the side of the lesion as compared with the opposite side.

With regard to this question of hyperæsthesia after hemisection of the spinal cord in animals there is a great divergence of opinion. It has not been obtained by all experimenters. FODÉRA was the first to observe this condition, but he did not invariably find it present. TÜRCK and BROWN-SÉQUARD also found it, and the latter considers it an *invariable* effect of hemisection. WEISS does not describe this condition, nor did FERRIER notice it in his experiment upon the Monkey. I have noticed it twice. It is looked upon by BROWN-SÉQUARD and his followers as a proof of the sensory decussation in the cord, especially when taken in conjunction with the fact that they state that there is anæsthesia in the opposite side of the body behind the lesion. LUDWIG and WOROSCHILOFF and MARTINOTTI explain the hyperæsthesia by the removal of influence of certain inhibitory fibres; but FERRIER states‡ that the hyperæsthesia on the side of lesion is only a sign by contrast of the diminished sensibility on the other side, and as a matter of fact ceases when the other lateral column is similarly divided, and both legs are reduced to the same level of sensibility.

This, however, is not strictly true, because MARTINOTTI made a bilateral injury of a

* [M. VULPIAN has found the sensory troubles following hemisection different in different kinds of animals. In the Dog, for example, he found a hyperæsthesia in the posterior limb on the side of the hemisection; he believes this to be due to a hyperexcitability produced in the elements of the spinal cord behind the lesion, and only on the side corresponding to it. When it is unilateral, M. VULPIAN considers the diminution of sensibility on the opposite side as a sort of effect of the hyperæsthesia. The slight difference of sensibility that he has found from experiment, appears to him to prove that the sensory impulses do not completely decussate in the spinal cord in Mammalia. M. VULPIAN considers the grey matter of the spinal cord as the principal conductor of sensory impressions. He does not, however, affirm that the white matter does not play any part in this transmission.—'Dictionnaire Encyclopédique des Sciences Médicales,' vol. 8, p. 384.]

† *Loc. cit.*

‡ *Loc. cit.*, p. 46.

great part of the lateral columns and a little of the left anterior horn* so as to involve that region which his and WOROSCHILOFF's experiments show to be connected with the production of hyperæsthesia. The result of this bilateral injury of the lateral columns was a hyperæsthesia of anterior and posterior limbs of both sides. Taking the experiments of BROWN-SÉQUARD referred to previously in conjunction with the results of the discovery of the path of the vaso-motor nerves of the lower limb, it might, perhaps, be considered that the hyperæsthesia was due to a vaso-motor disturbance on the side of the injury, by which the nerve-fibres become more excitable. Professor MICHAEL FOSTER argues against this view,† "because division of the cervical sympathetic does not give rise to hyperæsthesia, nor can we explain it as due to a one-sided hyperæmia of the spinal cord itself, for we have no evidence that such a state of things is brought about. Since it lasts for a very considerable time it cannot be due to any passing exciting effect of the operation. It has been suggested that the section in such cases has removed previously existing influences which, descending the cord, exercised an inhibitory action on the generation of sensory impulses—more particularly of those more complex impulses which we have supposed to arise in the local mechanism of grey matter with which the posterior roots are connected."

In cases where hyperæsthesia exists, all forms of stimulation give rise to pain. I think there are, however, objections to the acceptation of the view that hyperæsthesia on the side of the lesion affords a proof that the main part of the sensory impulses decussate almost immediately in the spinal cord.

Firstly, because BROWN-SÉQUARD's own experiments show that he could produce a similar effect to a hemisection by unilateral division of the lower dorsal and upper lumbar spinal nerves, the main effect of which, besides the hyperæsthesia of the same side and the anæsthesia of the opposite, was vaso-dilatation and rise of temperature of the body behind and on the side of the lesion.

Secondly, because it is not noticed in all cases of hemisection of the spinal cord.

Thirdly, MARTINOTTI's experiment shows that it may be produced on both sides of the body by a bilateral lesion.

FOSTER says we cannot explain the hyperæsthesia by hyperæmia of the spinal cord itself, for we have no evidence that such a state of things is brought about. A paper has just been published by BECHTEREW,‡ in which he ascribes the hyperæsthesia which occurs after section of the posterior columns as due to an inflammatory reaction of the grey substance, and in those cases of his in which hyperæsthesia occurred in the neighbourhood of the section of the posterior columns, the grey substance was

* *Loc. cit.*, p. 186.

† *Loc. cit.*, p. 606, 4th edition.

‡ "Ueber die Erscheinungen, welche die Durchschneidung der Hinterstränge des Rückenmarkes bei Thieren herbeiführt, und über die Beziehungen dieser Stränge zur Gleichgewichtsfunction." Von Prof. W. BECHTEREW. 'Archiv für Physiologie,' DU BOIS-REYMOND, 1890.

distinctly red, and, on microscopical examination, there was found a dilatation of the blood-vessels, or even development of vessels, not unfrequently accompanied by an exudation in the tissue, and especially a distinct cloudiness of the cell elements. On these grounds I am of opinion that the hyperæsthesia in such cases is brought about by irritation of sensory fibres, in consequence of inflammatory action, which occurs in the grey substance of the spinal cord. This does not account for a unilateral hyperæsthesia after hemisection, but I have examined sections of two cases in which there was distinct hyperæsthesia, and in one case I have made an examination of some Weigert stained sections. I find around the vessels plasmatic exudation and hæmorrhages into the grey matter. The animals were generally kept alive too long to find any evidences of inflammatory changes at the seat of the lesion.

HOMÈN* and OSAWA† did not notice any appreciable difference in sensibility on the two sides after hemisection, and the latter even found sensibility diminished on the side of the lesion.

Important work bearing upon this subject has lately been done by GOTCH and HORSLEY.‡

I will quote some of their general conclusions :—

Electrical changes in the spinal cord when evoked by direct excitation of its fibres after severance from the encephalon: 1st. High degree of unilaterality of representation in the spinal cord; 2nd. Spread of impulses from one posterior column to another, and from one posterior column to its neighbouring lateral column through centres.

The relation of the paths and of the bulbo-spinal centres in the spinal cord to the peripheral nerves and their roots: The electrical changes in the spinal cord evoked by excitation of a mixed nerve or its roots. The following general principles arrived at: 1. Complete destruction of centripetal impulses reaching the cord by the central end of the anterior root; 2. Mode of conduction, direct and indirect, in the cord, of centripetal impulses passing up the posterior root; 3. Localization of the direct path of afferent impulses in the posterior column of the same side as that of the nerve or root excited; 4. Localization of the indirect path of afferent impulses in the posterior columns of the same and the opposite side, and the lateral columns of the same side as that of the nerve excited; 5. Proportionate development of both systems of paths in the two sides of the cord, expressed in percentages of the total transmission :—

* *Loc. cit.*

† *Loc. cit.*

‡ Croonian Lecture, Royal Society, February, 1891, "On the Mammalian Nervous System, its Functions and their Localisation, determined by an Electrical Method," by FRANCIS GOTCH, Hon. M.A., Oxon., and VICTOR HORSLEY, F.R.S., B.S.; from the Physiological Laboratory, Oxford.

		Per cent.
Posterior column of same side as the excited nerve	. . . . .	60
Lateral ,, ,, ,,	. . . . . .	20
Posterior column of opposite side to the excited nerve	. . . .	15
Lateral ,, ,, ,,	. . . .	5

Experiment has led to many different views with regard to the conduction of sensory impulses in the spinal cord, and the subject seems full of contradictions, which may be partly accounted for by the experimenters having used different animals, by having made their experiments on different parts of the spinal cord, by different modes of experiment, and by different methods of testing the results of the experiment; and lastly, and not least, the different inferences which are drawn by the experimenters themselves. We have thus the following views:—

I. FERRIER. That all sensory impulses, *those of the muscular sense included*, decussate in the spinal cord and pass up the opposite side. This experimenter founds his proof upon an experiment on a Monkey, the details of which have already been quoted.

II. BROWN-SÉQUARD. All sensory impulses, *excepting those of the muscular sense*, decussate almost immediately, and pass up the opposite side. He founds his proof upon experiments made upon Dogs, Guinea Pigs, Rabbits, &c., and his view has been supported in a great measure by clinical observation.

III. SCHIFF. Painful impressions are conveyed in the grey matter on the opposite side after decussation, while tactile impressions pass up the columns of the same side. The proof of this is founded on experiments upon Dogs, Cats, Rabbits, &c. Some pathological cases seem to support this view.

IV. WOROSCHILOFF and MIESCHER. Afferent sensory impressions pass up both lateral columns, but more particularly by the lateral column of the opposite side, that is to say, most of the sensory impulses decussate, but not all. Experiments were made upon Rabbits.

V. WEISS, HOMÈN, and OSAWA. Painful sensory impulses from one side of the body pass up both lateral columns about equally. Experiments made upon Dogs.

VI. HORSLEY and GOTCH. Most afferent impulses pass up the same side of the cord. Their method does not enable them to differentiate the sensory impulses, and I am informed by Mr. GOTCH that they have not experimented above the 8th dorsal segment. For example, when they stimulate the sciatic nerve of the left side they have not ascertained the electrical results on the two sides of the cord above the 8th dorsal segment. Their experiments, however, are free from some of the fallacies which have arisen in testing the sensibility of the lower animals. Their results, as also those of WEISS, OSAWA, and HOMÈN, accord entirely with my own.

VII. My experiments show that painful sensations are conducted up both sides, as also is the sensation of heat. Touch and pressure sensations associated with localization are chiefly conducted up the same side, although, after a time, a collateral

channel may be developed, which becomes permanent, just as collateral channels are formed for the production of bilateral associated movements. Lastly, there can be little doubt that muscular sense-impressions pass up the same side.

The degenerations which result :—From section of the roots of the cauda equina* in the Monkey I have shown to be limited to the same side. There are two sets of fibres in the posterior columns, a long system—the fibres of the columns of GOLL, and another system—short fibres which ascend a variable distance in the postero-external column. Some of these fibres are connected with the cells of CLARKE'S column ; this has also been shown by TOOTH, BECHTEREW,† RAMON Y CAJAL, and KÖLLIKER. The fibres end in fine collaterals (according to the last two observers) around the cells of CLARKE'S column. According to BECHTEREW, also, fibres pass to cells of the posterior horn. So far, then, no decussation can have taken place, and the anatomical evidence, according to my experience, of an examination of many thousands of specimens, does not warrant the inference that fibres derived from the posterior roots decussate to any extent in the spinal cord. All this quite agrees with the results obtained by HORSLEY and GOTCH ; the small reaction which they obtained from the opposite posterior column on stimulating, may have been due to the commissural connections between the columns of CLARKE on the two sides ; moreover, hemisections, when quite unilateral, show no degeneration in the posterior column of the opposite side. There is little doubt, according to the observations of the before-named observers and my own, that the fibres of the direct cerebellar tract arise from the cells of CLARKE'S column. BECHTEREW concludes from his experiments, and from other data which he cites, that the fibres of the direct cerebellar tract, also of GOLL'S column and of BURDACH'S column, serve for a second centripetal conducting tract for the maintenance of balance, and are possibly connected in a way with the muscles.

The direct cerebellar tract ends above in the restiform body which goes to the cerebellum. According to BECHTEREW, this has nothing to do with touch, nor has the posterior median column, which is supposed, however, by some authorities to be connected with the muscular sense. We have then only one other long tract, which degenerates right up the cord, which can convey other sensations, such as touch, heat and cold, and painful sensations. This is the antero-lateral ; it degenerates on the same side above a hemisection. In my opinion no sufficient evidence has been brought forward by GOWERS for his views with regard to the origin of this tract from fibres coming from the opposite side of the cord ; nor by EDINGER for his view that these fibres come from cells of the posterior horn of the opposite side, the nerve processes of which decussate over in the anterior commissure. In fact, like the fibres of the direct cerebellar tract, they appear to me to come from cells of the same side. The experiments of GOTCH and HORSLEY support this view. The electrical reaction of the lateral column of the same side on stimulation of a posterior root is four times that of the

* 'Brain,' *loc. cit.*

† *Loc. cit.*

opposite. What the function of this column is, is not known. It decreases in size at the lower part of the medulla, and disappears in the arciform fibres, as my specimens show. There is no proof that it conducts painful sensations, only surmise.

Another possible channel for the transmission of sensory impulses upwards is the grey matter. This is SCHIFF's view, and there is much to support it from pathological observations, notably cases of syringo-myelia;* although WEISS's experiments on the Dog, and those of BROWN-SÉQUARD, distinctly oppose such a theory. But it is possible to conceive that the grey matter is connected at different levels by a series of short ascending commissural connecting fibres. The sensory elements are thus brought into relation with one another, just as we believe the motor cell elements are. Above a hemisection there is always a very extensive degeneration in the whole of the lateral column except the crossed pyramidal tract, which degeneration diminishes upwards until none is left except that belonging to the two long tracts of the lateral column. Of course, some of these degenerated fibres are fibres on their way to form these two tracts, as I have previously shown; but the great bulk are short ascending internuncial fibres.

So far, I have only dealt with the experimental side of the question. I have still to give a brief *résumé* of the more important facts which clinical practice and pathological examination afford.

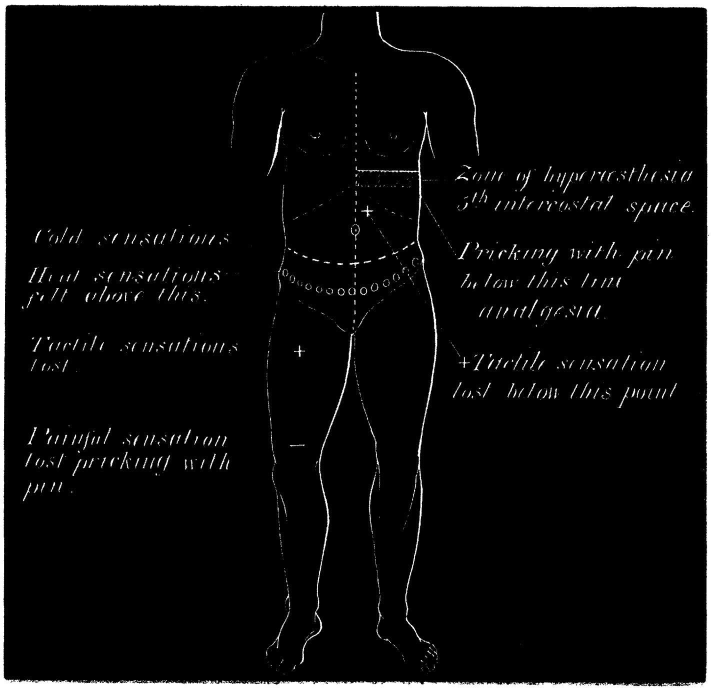
On the experimental side, we have little difficulty in exactly localizing the lesion, and the fallacies arise when we come to test the results of it, for nothing is more difficult than to test the different forms of sensibility in animals. This objection, however, which is always raised by purely clinical observers, is not so great in the Monkey as in the Dog, as I think the results of my experiments show.

On the other hand, experimental physiologists retort—the lesion in clinical cases can never be localized with any degree of precision, as it arises from accident or disease, and, unfortunately, with very few exceptions indeed, the *post-mortem* examination and subsequent microscopical research have either not been made at all, or inefficiently, so that the exact nature of the lesion has been involved in obscurity. I

* Dr. BLOC states that the microscopic changes consist in a neoplastic hyperplasia of the neuroglia of the grey or gliomatous matter, or a myelitis. The chief seat of the pathological change is around the central canal and in the gelatinous substance of ROLANDO. "If one examines the state of the sensibility one observes this peculiarity, almost pathognomonic, that, while sensibility to touch is perfectly retained, sensibility to pricking, as well as that to heat and cold, are completely abolished, not only in the upper extremities, but over more or less extensive areas, and sometimes over the whole body." "These forms of sensibility are unaffected—sensibility to touch, the muscular sense, and the special senses."—'Brain,' Part III., 1890: "Syringo-Myelia," by Dr. PAUL BLOC, Chef des Travaux Anatomo-Pathologiques à la Salpêtrière; translated by H. W. MARETT TIMS, M.B. Edin. Cases of syringo-myelia have been recorded by LEYDEN and Dr. HENRY BERKELEY, in which the loss of sensation and the paralysis were on the same side. "Syringo-Myelia," by HENRY J. BERKELEY, M.D., Baltimore. 'Brain,' Part 48; *vide* also a paper by JOFFROY and ACHARD, "Nouvelle autopsie de maladie de Morvan," 'Archives de Médecine Expérimentale,' 1891.

have approached this question from both sides. Four years ago, I believed implicitly in BROWN-SÉQUARD'S theory of immediate decussation of the sensory impulses, and with an unfortunate result, as the following case will show, reported fully in 'Brain,' 1887.*

Fig. 2.



The case was one of tumour beginning in the 5th left intercostal nerve. A cyst was subsequently formed which pressed upon the left side of the cord causing *numbness and weakness in the left* leg, then of the right, but not so marked. When the patient was admitted in Charing Cross Hospital I carefully tested his condition and made the accompanying diagram (fig. 2) to represent the condition of the sensory disturbance. It will be observed that sensibility to different forms of stimulus is at different levels on the two sides.

It tends to show that pricking, tactile, heat, and cold sensations pass by different paths, but it also shows anæsthesia and analgesia at a lower level upon the right than the left side (the seat of origin of the tumour). As the tumour increased in size, the right leg became more involved. It is right to remark in connection with this case, that I considered it one of tumour pressing upon the spinal cord, and that I advocated operation, but it was urged against my opinion that there should have been the more marked sensory disturbance *on the side opposite* to the tumour.†

* "Myxo-fibroma of the Spinal Cord." BRUCE and MOTT. 'Brain,' Part 38, 1887.

† The autopsy showed conclusively the fallacy of accepting too rigidly any dogma in medicine.

Dr. GOWERS and Mr. HORSLEY* have collected fifty-eight cases of tumour pressing upon the spinal cord. Of these seven are more or less unilateral. Only one case conclusively supports BROWN-SÉQUARD'S views, and this, I think, loses weight for reasons which I will endeavour to show.

These authors remark, p. 412, "Careful observation of such cases (as, for example, No. 50), indeed, reveals, in some instances, pathological effects such as make the condition tantamount to hemisection of the spinal cord, so that we have reproduced clinically the classical experiment of BROWN-SÉQUARD." In the tabular statement the following appears :—

"*The Position of the Tumour.*—(?) Between 8th and 9th dorsal vertebræ on anterior surface of *left antero-lateral column*, 5 centims. above the broadest part of the lumbar enlargement."

"*Effect on Cord.*—The left half of the cord was severed, crushed, and excavated by the growth, which pushed the median sulcus to the right and backwards. At the seat of compression, the cord was softened, grey, and gelatinous. Microscopic examination: Above the growth, there was ascending degeneration in *the posterior column, most marked on the right side;* below there was descending degeneration (grey) in the posterior part of the lateral columns, also most marked on the left side."

This account would tend to show that the pressure was oblique, and if so, would afford a different means of explanation. (Mr. HORSLEY has since expressed the same view to me.)

There are three traumatic cases which have occurred in Man and which have been followed by an autopsy, and I will give a brief account of these cases. As reported, they certainly support the view that painful sensations decussate, that is to say, if we accept hyperæsthesia as an indication of increased sensibility of one side. They do not, however, prove that tactile sensations decussate.

1. The case described by W. MÜLLER,† an abstract of which is given by KÖBNER.‡ The injury led to division of the whole left half of the spinal cord at the level of the fourth dorsal vertebra, and involved nearly all the right posterior column.

On the left side: Motility of arm preserved, of leg lost, temperature of left leg somewhat lower than that of right. Insensibility to touch. Sensibility to more intense stimuli. Highly sensitive to pressure. The abdominal muscles of this side appear paralyzed. During the illness paroxysms of pain frequently appear radiating from the wound and also spasmodic jerks in arm and leg. Hyperæsthesia at first great, but it subsided on the seventh day *and afterwards complete anæsthesia existed.*

On the right side: The leg at first freely moveable, on the seventh day it became

* "A case of Tumour of the Spinal Cord—Removal—Recovery," by W. R. GOWERS, M.D., F.R.S., and VICTOR HORSLEY, B.S., F.R.S., 'Medico-Chirurgical Transactions,' vol. 71.

† 'Beiträge zur pathologischen Anatomie und Physiologie des Menschlichen Rückenmarkes.'

‡ *Loc. cit*

distinctly paralyzed. Anæsthesia below the fourth intercostal space. Girdle sensation around the lower part of thorax. Death occurred after six weeks.

Autopsy.—Spinal cord severed 2 millims. below the third dorsal nerve, extending from the right side behind to the left in front. Posteriorly, the cut extends about 0·5 millim. beyond the place of exit of the posterior roots. Specimens showed that the left half, the right posterior column, and the right half of the commissure were severed. The grey matter of the right half, the right lateral and anterior columns were not injured.

This case certainly strongly supports the view that BROWN-SÉQUARD taught. I would only remark that, (1), looking at the position of the spines of the vertebræ in the upper dorsal region, the instrument which caused the stab must have passed somewhat obliquely upwards; (2), there must have been also considerable degenerative changes in the right lateral and anterior columns, or there would not have been anæsthesia and paralysis of both sides on the seventh day.

II. The second case is that of WEISS.* ECKHARD† remarks that this case would have been more instructive if the lesion had been more accurately described. No microscopical examination is reported. The injury was between the atlas and the skull, and the cord was hemisected in the uppermost segment. There was paralysis of the side injured, anæsthesia of the opposite side, hyperæsthesia of the same side.

III. A case of unilateral gunshot injury described by Dr. GOWERS.‡ This case is very instructive, although necessarily a lesion made by a spicule of bone is coarse. Microscopical examination in this case was made and the injury figured. I shall content myself with quoting *the remarks* of the author on the case.

"The injury to the cord in this case, although a bruise, was so limited as to produce the effect of a unilateral section of the cord in the upper part of the cervical region, destroying the continuity of the anterior and lateral columns and the anterior and posterior cornua on the right side, the posterior columns being uninjured except by œdema. The resulting interference with the function of the cord is of considerable interest in relation to the results of experimental investigation, and of clinical observations in other cases.

"1. Motive power was lost at first completely in the limbs on the same side as the lesion, but was preserved on the opposite side. The right side of the chest moved in respiration, but less than the left.

"The day after the injury there was slight return of the power of moving the leg.

"2. Sensation was very *distinctly diminished* on the left side (opposite the injury), on the right there was increased sensibility to pain. On the trunk sensation was normal as low as the nipple, below that it was increased on the right side, diminished on the left.

* LANGENBECK'S 'Archiv für Klin. Chir.,' vol. 21, pp. 2, 26.

† *Loc. cit.*

‡ 'Clinical Society's Transactions,' vol. 11.

"*Examination was difficult on account of patient's state.*"

It is to be assumed, therefore, that the sensory path from the middle and upper cervical nerves only crosses at the highest part of the cord above the level of the injury.

The injury to the cord in this case involved both antero-lateral columns and adjacent portions of grey matter. It affords, therefore, no evidence as to the path of common sensation, whether in the white or grey substance, which is still in dispute. The temperature on the side of the lesion was 1° F. higher than the opposite side. Dr. GOWERS seemed to think that this case supported in a measure SCHIFF'S views, but he has since changed his opinion, judging from the remarks in his book on the spinal cord.

The ultimate solution of the question rests upon an accurate *unbiassed* record of cases of disease and injury in Man, and, with the improved methods of microscopical research at our disposal, we shall, guided by physiological experiment, eventually come to a correct understanding of the path of conduction and the functions of the spinal cord.

[*Note, January* 20, 1892.—A paper "On Hemisection of the Spinal Cord," by WM. ALDREN TURNER, M.B. Edin., M.R.C.P., has lately appeared in 'Brain' (Winter Number, 1891).]

EXPLANATION OF PLATES* 1–4.

PLATE 1. (Photographs 1–11.)

The Lesions.

1.—Case I. The lesion between the 3rd and 4th dorsal nerves. This is not a perfect hemisection; all the lateral column has been destroyed, but a portion of the posterior column and that portion of the anterior column which lies internal to the anterior horn contain both undegenerated and degenerated fibres. Other sections showed more degeneration in the anterior column.

2.—Case II. The lesion at the last dorsal segment. The animal only lived 24 days, therefore the sclerosis is not marked; the line of incision, however, shows that the lesion was complete with the exception of the anterior and posterior median columns.

3.—Case VII. The lesion at the 3rd dorsal. The animal lived 115 days. The photograph is not through the lesion, but just above it, showing degeneration in the antero-lateral, the postero-external, and direct cerebellar tracts,

* The photographs have all been made from the original untouched negatives.

and a general shrinking of the whole left half of the spinal cord. The lesion spared the posterior median column.

4 and 5.—Case III. Lesion between 5th and 6th dorsal roots. These photographs show the injury to have been as nearly as possible a complete hemisection, without involving the opposite side of the cord; a small portion of the posterior median column close to the middle line may have been spared, but this must have been inconsiderable, for the degenerations in Plates 2 and 3 show how very complete the hemisection must have been, anteriorly, because the degeneration occurs in this region down to the furthermost limit of the cord; posteriorly, as shown by the degeneration in GOLL'S column.

6 and 7.—Case V. Lesion at 6th dorsal. Three hemisections made at 2 or 3 mm. apart. Fig. 7 is through the lesion, and the cord is so destroyed as to be hardly recognisable. Great difficulty was experienced in cutting sections through the lesions, owing to the formation of very dense fibrous tissue. Practically the grey matter at the seat of the lesion is destroyed, as can be seen by the photograph. The white matter of the postero-external and lateral columns on the side opposite to the lesion is for the most part intact. Fig. 6, section at 4th dorsal, shows that the degeneration is not limited to the side of the lesion, although that is much more extensive. Perhaps this may have been due to the pressure of the fibrous nodule found at the seat of the lesion adherent to the cord. The interest of this case lies, however, in the fact that on the side of the lesion, and where the greatest amount of degeneration existed, there was anæsthesia and analgesia (*vide* p. 9 and fig. 4, Plate 3).

8.—Case VI. Lesion at 6th dorsal. The destruction is very complete in one half of the cord, and the anterior and posterior median columns of the other side contain very many degenerated fibres. Moreover, above the lesion there was scattered degeneration of the antero-lateral and direct cerebellar tracts of the opposite side, probably due to the injury of the grey matter 10 days previous to the hemisection (*vide* p. 11).

9.—Case IV. Lesion at the level of the 6th dorsal segment. A portion of the posterior column not injured, but the whole of the antero-lateral (*vide* also fig. 2, Plate 3).

10.—Case IX. Lesion at the level of 6th and 7th dorsal. The injury was so extensive as to have altered the appearance of the spinal cord in section. The area of absolute destruction is shown in fig. 4, Plate 3. Above and below the lesion there was degeneration in both lateral columns, and the posterior column at the seat of lesion was practically destroyed, even on the opposite side to the attempted hemisection.

11.—Case VIII. Lesion at the level of the 3rd cervical. This section was made from

the upper surface of the portion of the cord below the gap. The posterior column appears almost uninjured. There was, however, complete degeneration in the sections above the lesion, and this was not entirely limited to the posterior column of the side of the lesion, but affected to some extent the opposite posterior column.

Fig. 1 represents the appearance of the spinal cord in the cervical region, *a*, anteriorly, *p*, posteriorly seen. The gap in the cord was oblique.

PLATE 2. (Photographs 12–23.)

The degenerations resulting from a hemisection of the spinal cord at the 5th and 6th dorsal, Case III. (*vide* also Plate 1, photos. 4 and 5).

12.—2nd cervical. The degenerated direct cerebellar tract separated from the periphery. The degenerated antero-lateral tract in front of this and GOLL's column degenerated on one side.

13.—4th cervical segment.

14.—6th cervical segment.

15.—8th cervical segment.

16.—2nd dorsal segment.

17.—4th dorsal segment. Degeneration seen extending across the lateral column in front of the pyramidal tract and merging into the antero-lateral tract. The degenerated direct cerebellar tract is at the periphery of the cord. (Compare with the next.)

18.—5th dorsal, just above lesion. Considerable degeneration in the ground fibres. The degenerated direct cerebellar tract can be seen passing outwards along the posterior horn. A small portion of root fibres in the posterior column undegenerated, probably descending fibres.

19.—The lesion, *vide* also 4 and 5, Plate 1.

20.—0·5 centimetre below the lesion. Comma-shaped tract of degeneration of the posterior column, *vide* also Plate 4, fig. 10. Descending degeneration in the pyramid and at the periphery of the antero-lateral column, *vide* fig. 1, text p. 26.

21.—10th dorsal. The pyramidal degeneration is not so well shown.

22.—2nd lumbar segment.

23.—4th lumbar segment.

PLATE 3. (Photographs 24–27.)

24.—5th lumbar segment.

25.—Sacral segment.

26.—Coccygeal segment.

Photos. 25 and 26 show well the degeneration in the antero-lateral region and the pyramidal tract. These sections were stained by a new method devised by Professor SCHÄFER, especially valuable for photographic reproduction, hence the degeneration is better shown than in the other sections below the lesion although much more remote.

27.—The brain and portion of cortex removed therefrom in Case VII.

Figs. 2, 3, 4 are tracings of the photos. of lesions shown in Plate 1.

2 corresponds to 9, Plate 1, Case IV.
3 ,, 8, ,, Case V.
4 ,, 10, ,, Case IX.

The dark portion represents the area of absolute destruction.

PLATE 4.

[Photographs of the sections were sent with the paper, but as there was some doubt about reproducing them with sufficient clearness, prints taken from the negatives were given to Mr. COLLINGS together with the specimens, and he has faithfully reproduced the same.]

Fig. 5.—Section at the 8th dorsal segment, Case III. The direct cerebellar fibres have reached the periphery and are seen as a distinct tract of undegenerated fibres.

Fig. 6.—Section at the 10th to 11th dorsal segment. The degenerated fibres of the pyramidal tract extend up to the periphery, the fibres of the direct cerebellar tract have not yet passed through the lateral column.

Fig. 7.—The degenerated pyramidal tract at the level of the 11th dorsal. Numerous large healthy fibres scattered among the degenerated. These are presumably fibres on their way to the direct cerebellar and the antero-lateral tracts.

Fig. 8.—The degenerated antero-lateral tract at the upper part of the medulla intersecting the arciform fibres.

Fig. 9.—Descending degeneration of the periphery of the anterior column at the level of 2nd lumbar.

All the above are magnified about 150 diameters.

Fig. 10.—The comma-shaped degeneration (shown also in Plate 2, No. 20), magnified about 70 diameters.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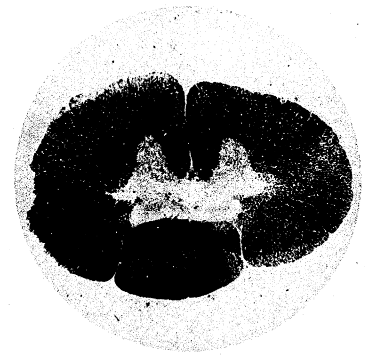
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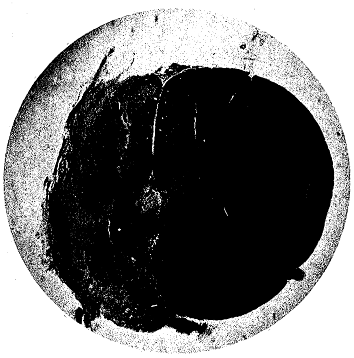
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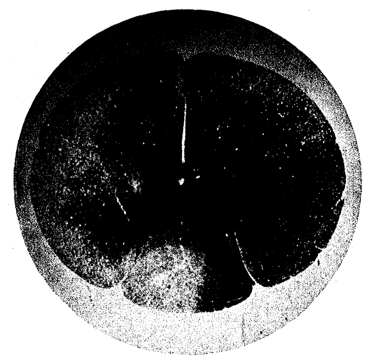
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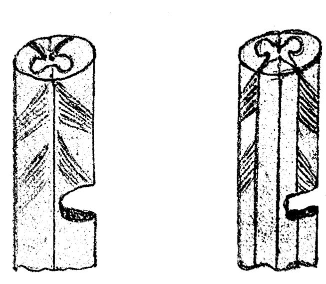
FIG. 1.


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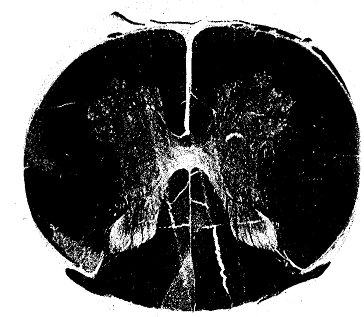

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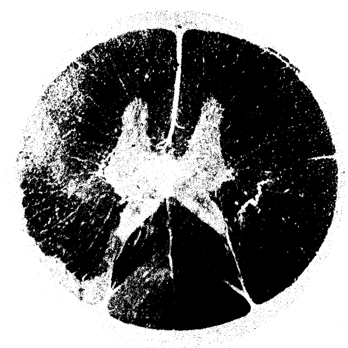

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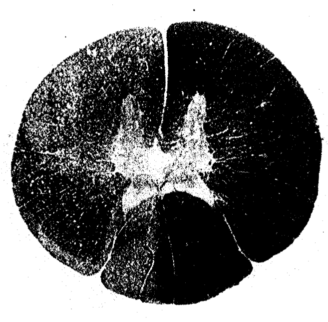

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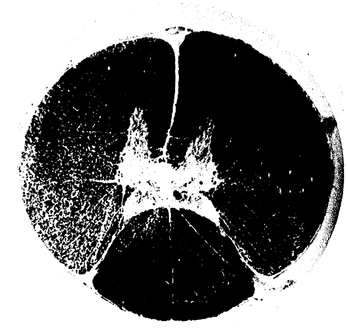

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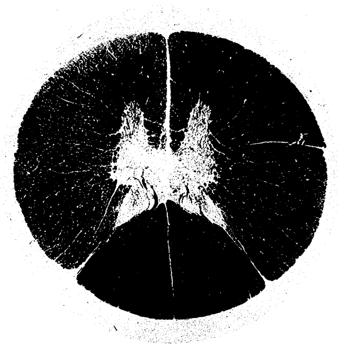

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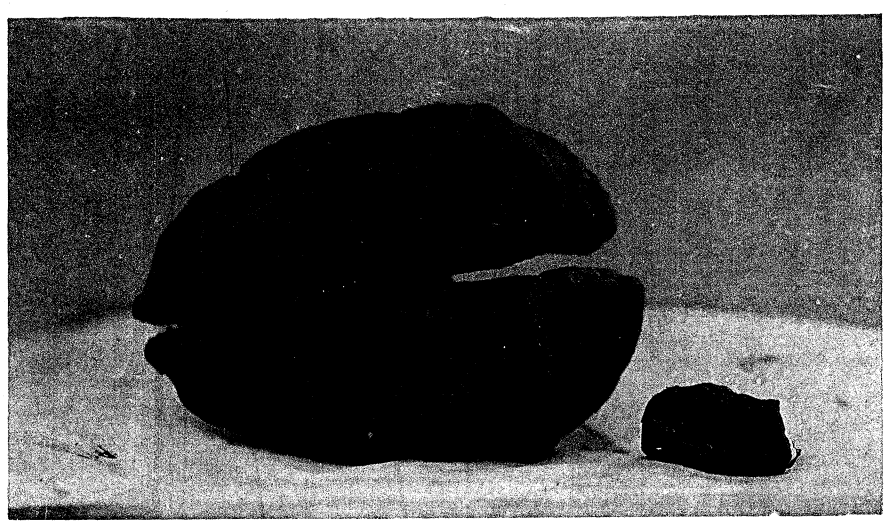

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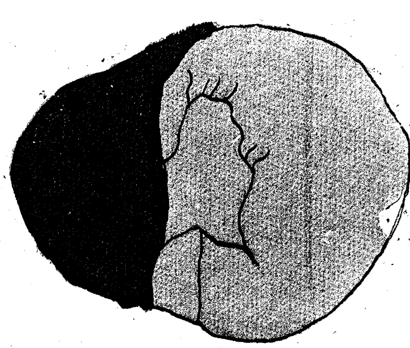

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FIG. 3.

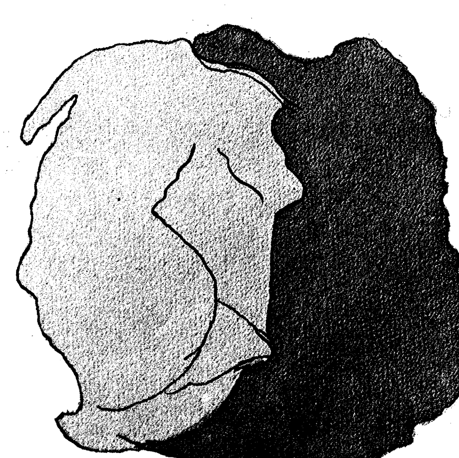

FIG. 4.

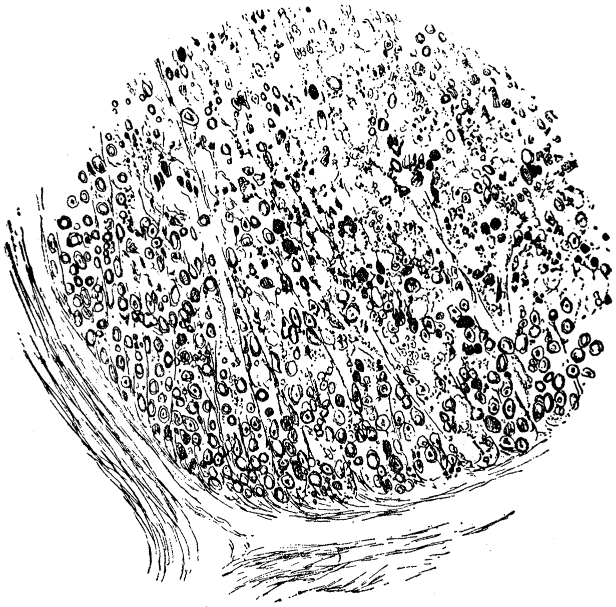

Fig. 5.

Fig. 6.

Fig. 8.

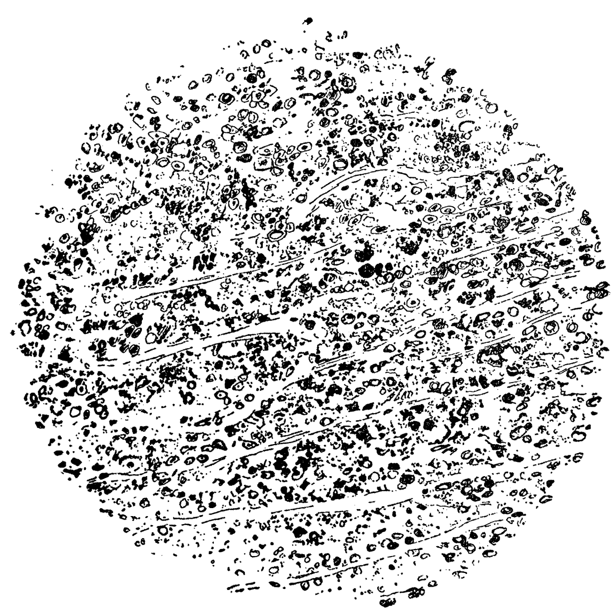

Fig. 7.

Fig. 9.

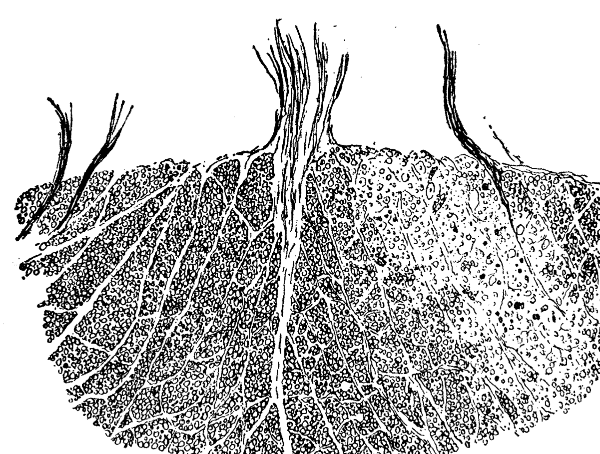

Fig. 10.

T. P. Collings, del. West, Newman, imp.

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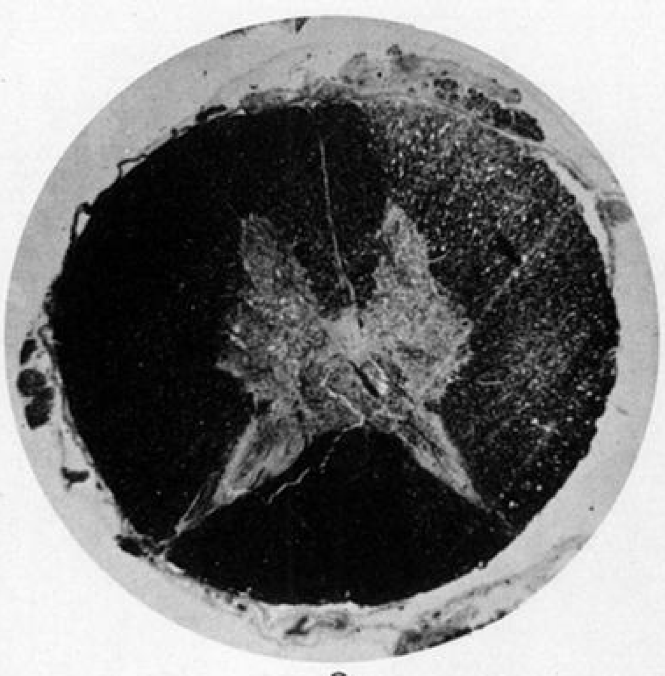

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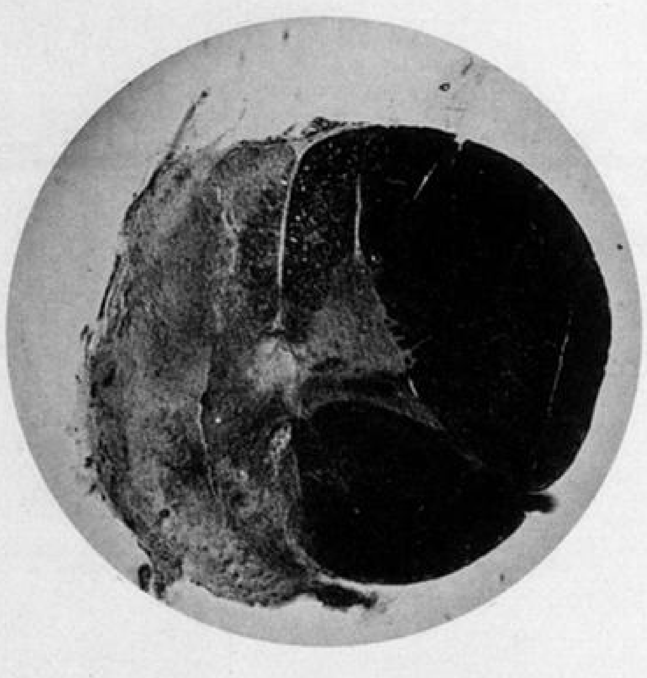

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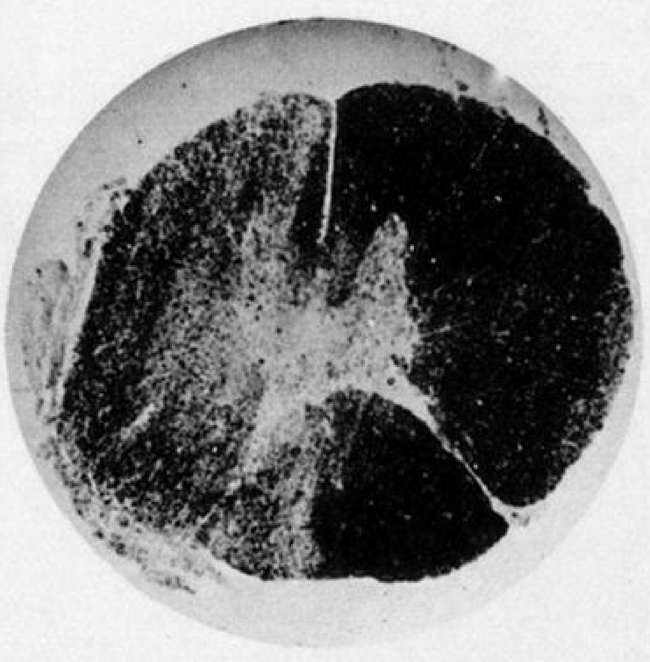

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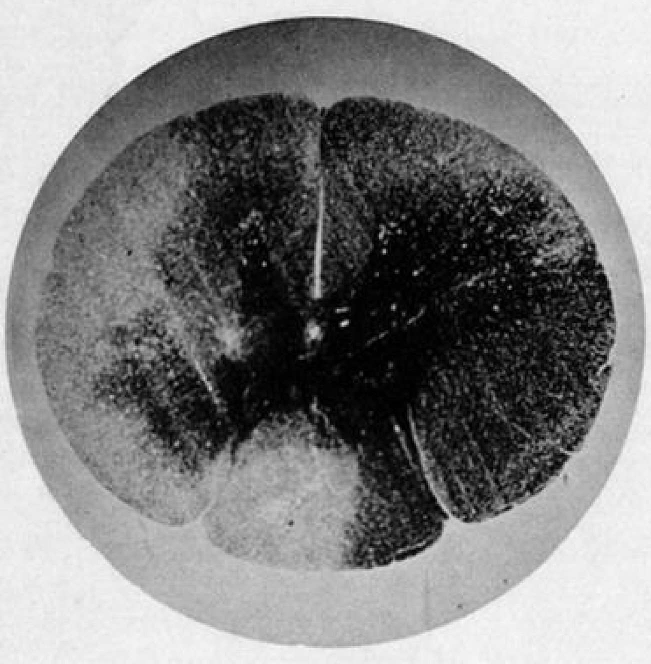

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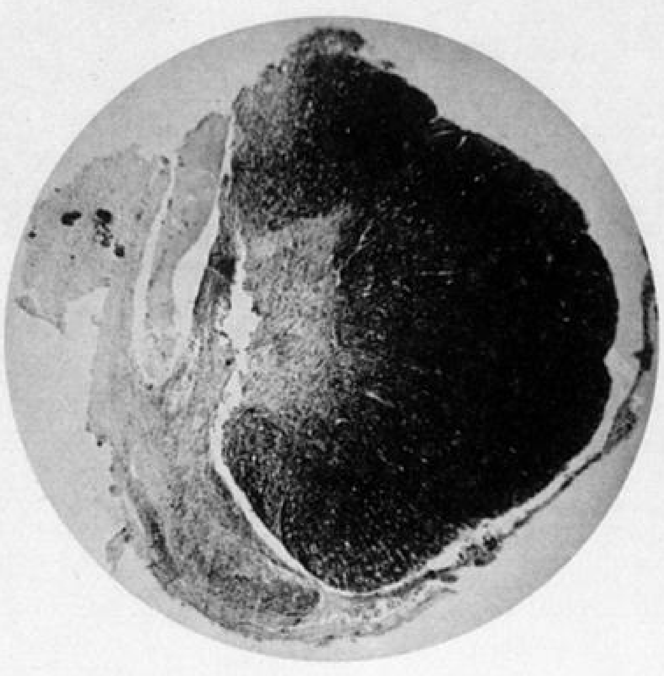

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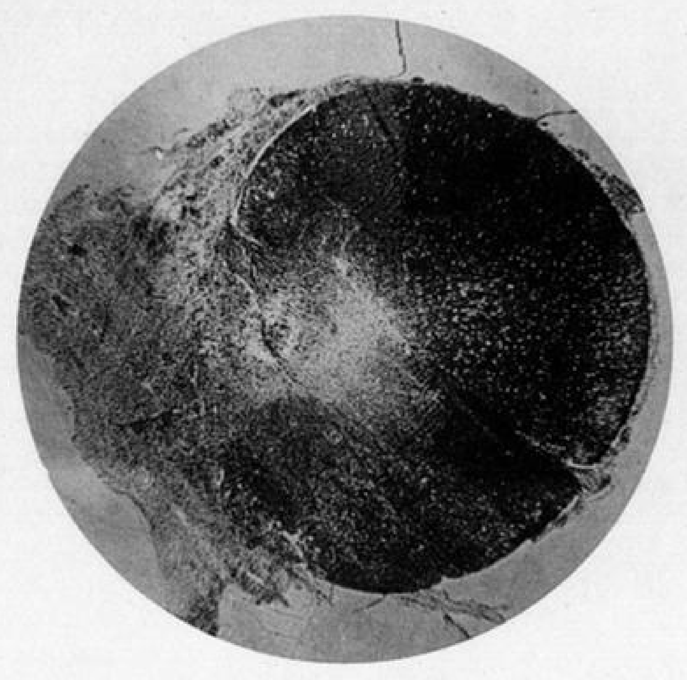

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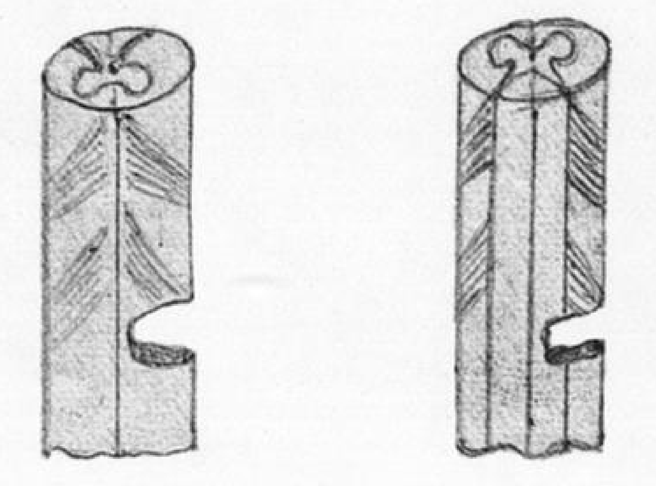
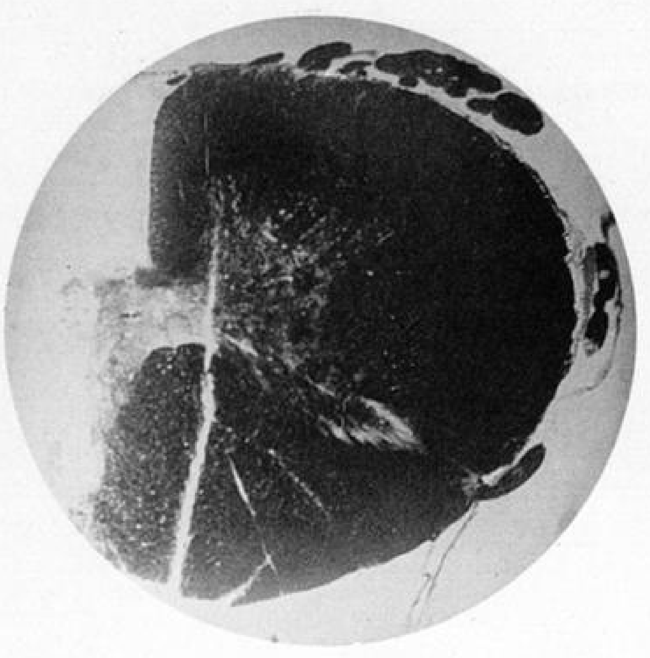


FIG. 1.



11.

PLATE 1. (Photographs 1–11.)

The Lesions.

1.—Case I. The lesion between the 3rd and 4th dorsal nerves. This is not a perfect hemisection; all the lateral column has been destroyed, but a portion of the posterior column and that portion of the anterior column which lies internal to the anterior horn contain both undegenerated and degenerated fibres. Other sections showed more degeneration in the anterior column.

2.—Case II. The lesion at the last dorsal segment. The animal only lived 24 days, therefore the sclerosis is not marked; the line of incision, however, shows that the lesion was complete with the exception of the anterior and posterior median columns.

3.—Case VII. The lesion at the 3rd dorsal. The animal lived 115 days. The photograph is not through the lesion, but just above it, showing degeneration in the antero-lateral, the postero-external, and direct cerebellar tracts, and a general shrinking of the whole left half of the spinal cord. The lesion spared the posterior median column.

4 and 5.—Case III. Lesion between 5th and 6th dorsal roots. These photographs show the injury to have been as nearly as possible a complete hemisection, without involving the opposite side of the cord; a small portion of the posterior median column close to the middle line may have been spared, but this must have been inconsiderable, for the degenerations in Plates 2 and 3 show how very complete the hemisection must have been, anteriorly, because the degeneration occurs in this region down to the furthermost limit of the cord; posteriorly, as shown by the degeneration in GOLL'S column.

6 and 7.—Case V. Lesion at 6th dorsal. Three hemisections made at 2 or 3 mm. apart. Fig. 7 is through the lesion, and the cord is so destroyed as to be hardly recognisable. Great difficulty was experienced in cutting sections through the lesions, owing to the formation of very dense fibrous tissue. Practically the grey matter at the seat of the lesion is destroyed, as can be seen by the photograph. The white matter of the postero-external and lateral columns on the side opposite to the lesion is for the most part intact. Fig. 6, section at 4th dorsal, shows that the degeneration is not limited to the side of the lesion, although that is much more extensive. Perhaps this may have been due to the pressure of the fibrous nodule found at the seat of the lesion adherent to the cord. The interest of this case lies, however, in the fact that on the side of the lesion, and where the greatest amount of degeneration existed, there was anæsthesia and analgesia (*vide* p. 9 and fig. 4, Plate 3).

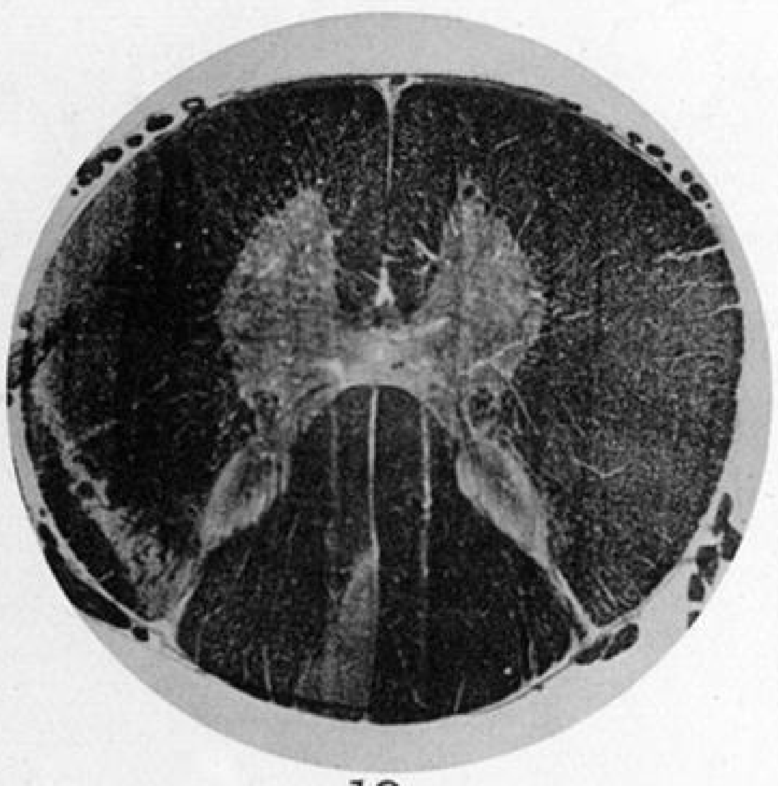
8.—Case VI. Lesion at 6th dorsal. The destruction is very complete in one half of the cord, and the anterior and posterior median columns of the other side contain very many degenerated fibres. Moreover, above the lesion there was scattered degeneration of the antero-lateral and direct cerebellar tracts of the opposite side, probably due to the injury of the grey matter 10 days previous to the hemisection (*vide* p. 11).

9.—Case IV. Lesion at the level of the 6th dorsal segment. A portion of the posterior column not injured, but the whole of the antero-lateral (*vide* also fig. 2, Plate 3).

10.—Case IX. Lesion at the level of 6th and 7th dorsal. The injury was so extensive as to have altered the appearance of the spinal cord in section. The area of absolute destruction is shown in fig. 4, Plate 3. Above and below the lesion there was degeneration in both lateral columns, and the posterior column at the seat of lesion was practically destroyed, even on the opposite side to the attempted hemisection.

11.—Case VIII. Lesion at the level of the 3rd cervical. This section was made from the upper surface of the portion of the cord below the gap. The posterior column appears almost uninjured. There was, however, complete degeneration in the sections above the lesion, and this was not entirely limited to the posterior column of the side of the lesion, but affected to some extent the opposite posterior column.

Fig. 1 represents the appearance of the spinal cord in the cervical region, *a*, anteriorly, *p*, posteriorly seen. The gap in the cord was oblique.



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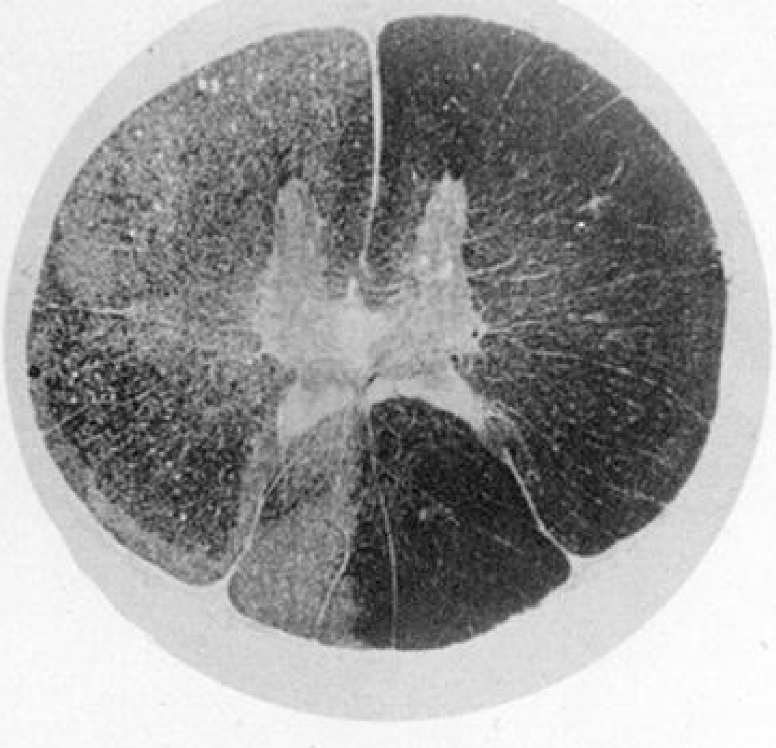

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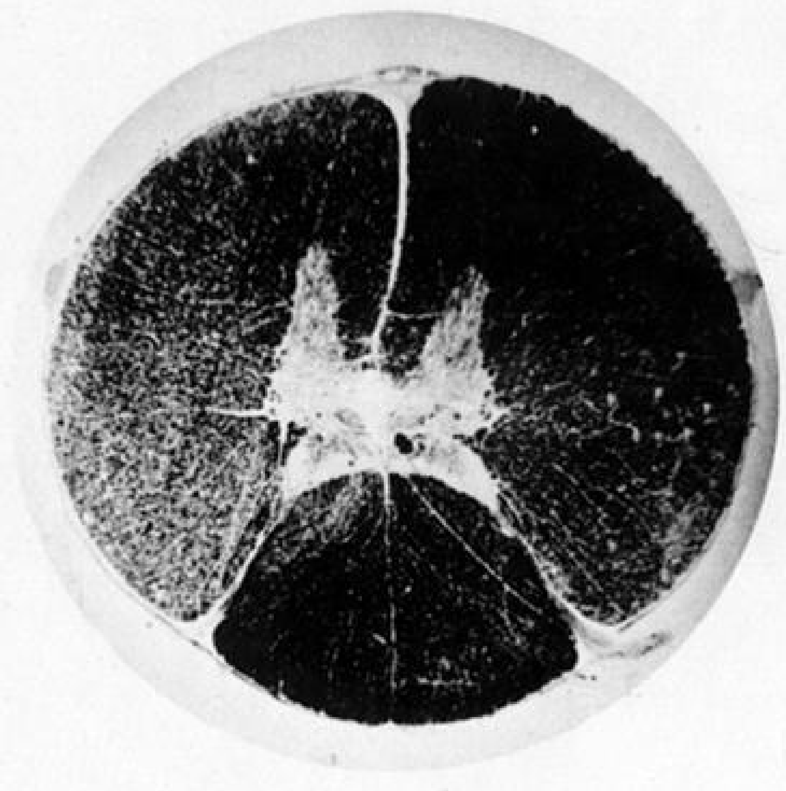

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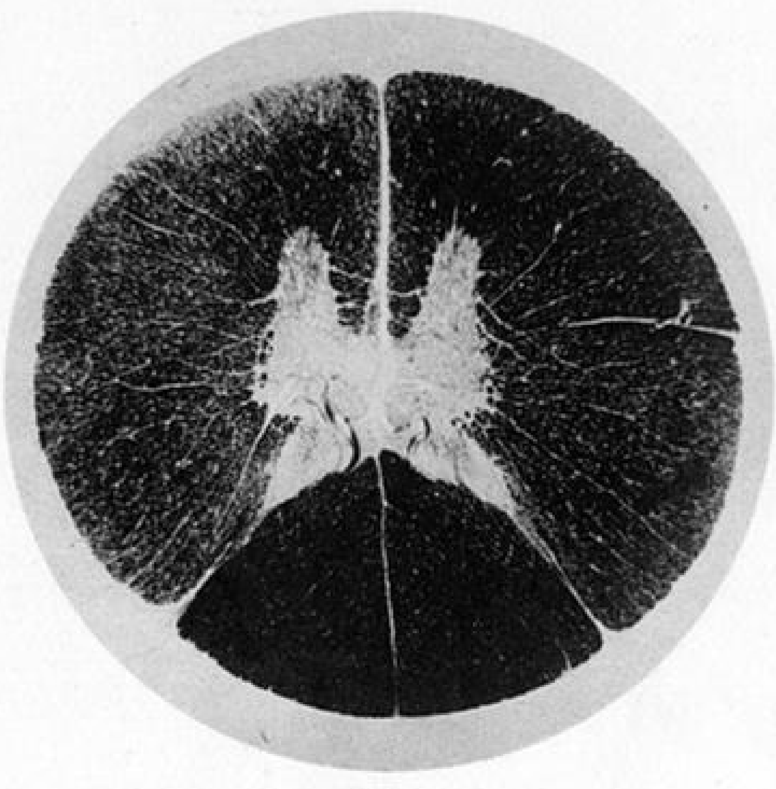

21.

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PLATE 2. (Photographs 12–23.)

The degenerations resulting from a hemisection of the spinal cord at the 5th and 6th dorsal, Case III. (*vide* also Plate 1, photos. 4 and 5).

12.—2nd cervical. The degenerated direct cerebellar tract separated from the periphery. The degenerated antero-lateral tract in front of this and GOLL'S column degenerated on one side.

13.—4th cervical segment.

14.—6th cervical segment.

15.—8th cervical segment.

16.—2nd dorsal segment.

17.—4th dorsal segment. Degeneration seen extending across the lateral column in front of the pyramidal tract and merging into the antero-lateral tract. The degenerated direct cerebellar tract is at the periphery of the cord. (Compare with the next.)

18.—5th dorsal, just above lesion. Considerable degeneration in the ground fibres. The degenerated direct cerebellar tract can be seen passing outwards along the posterior horn. A small portion of root fibres in the posterior column undegenerated, probably descending fibres.

19.—The lesion, *vide* also 4 and 5, Plate 1.

20.—0·5 centimetre below the lesion. Comma-shaped tract of degeneration of the posterior column, *vide* also Plate 4, fig. 10. Descending degeneration in the pyramid and at the periphery of the antero-lateral column, *vide* fig. 1, text p. 26.

21.—10th dorsal. The pyramidal degeneration is not so well shown.

22.—2nd lumbar segment.

23.—4th lumbar segment.

24.

25.

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27.

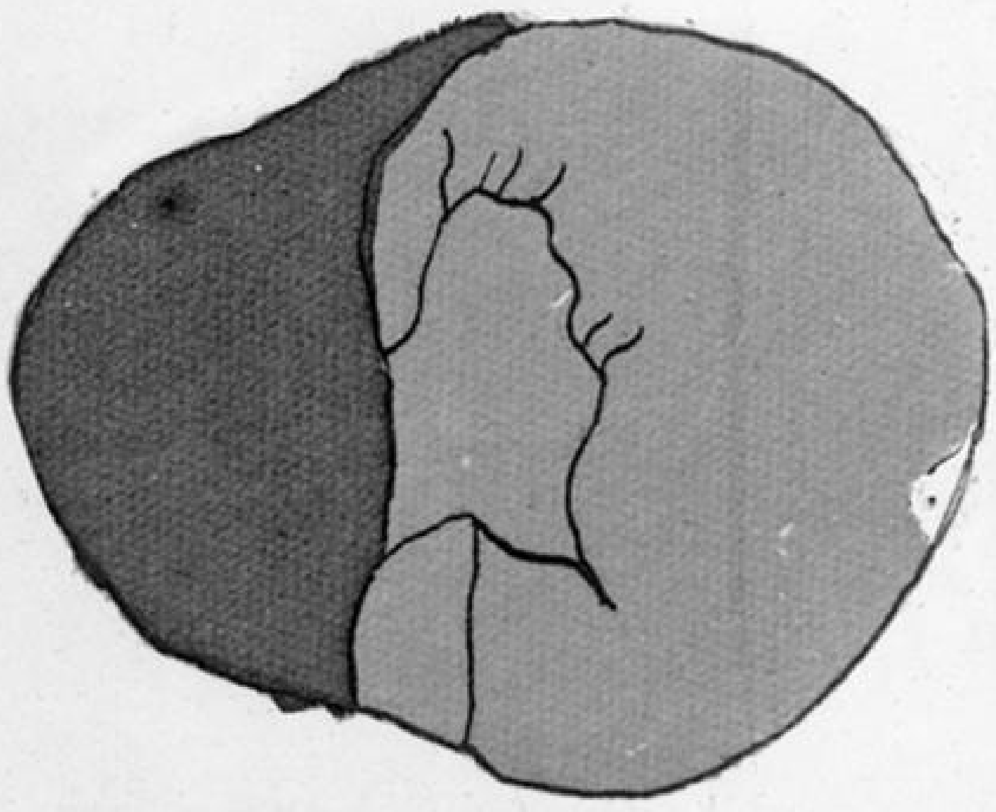

FIG. 2.

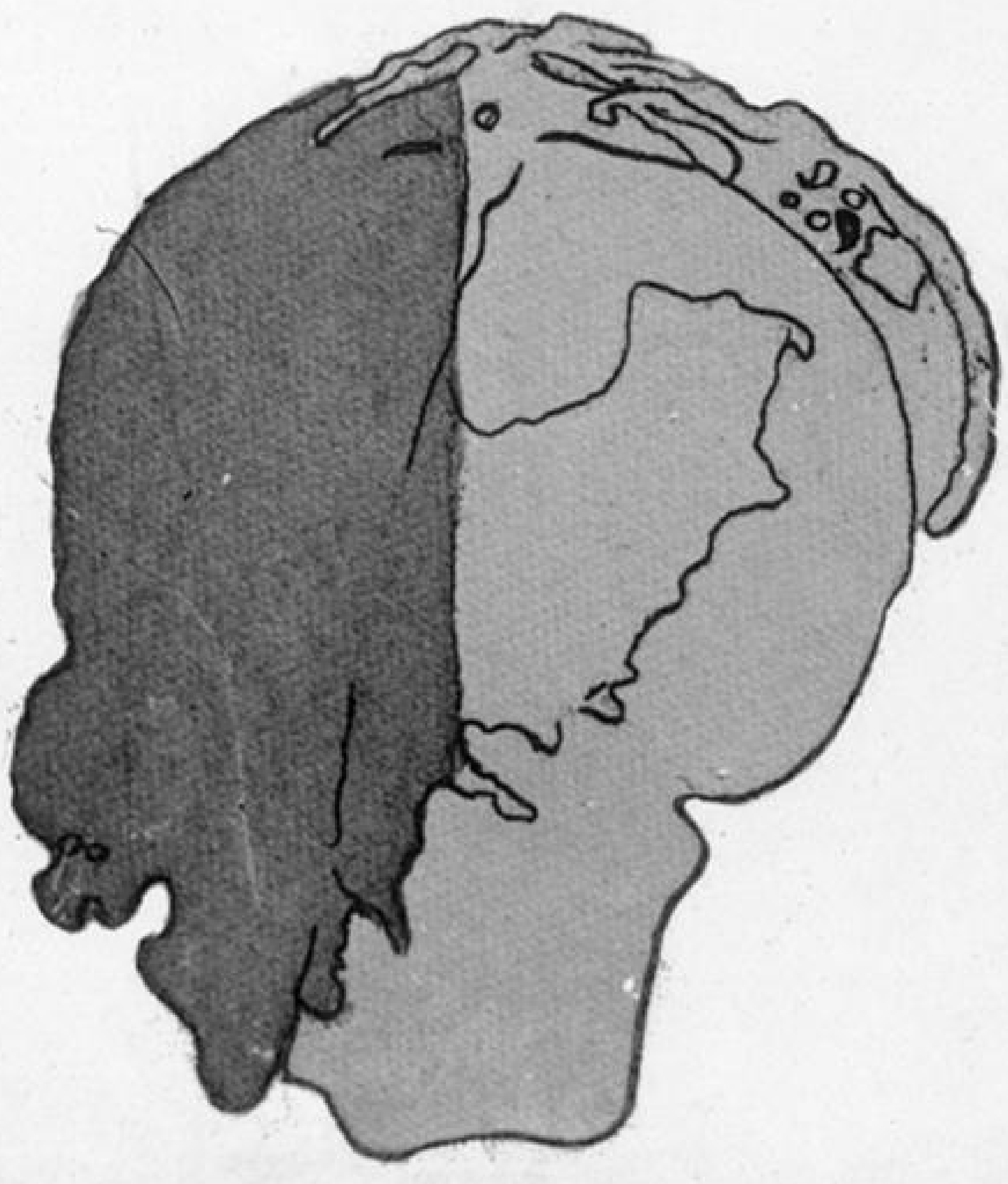

FIG. 3.

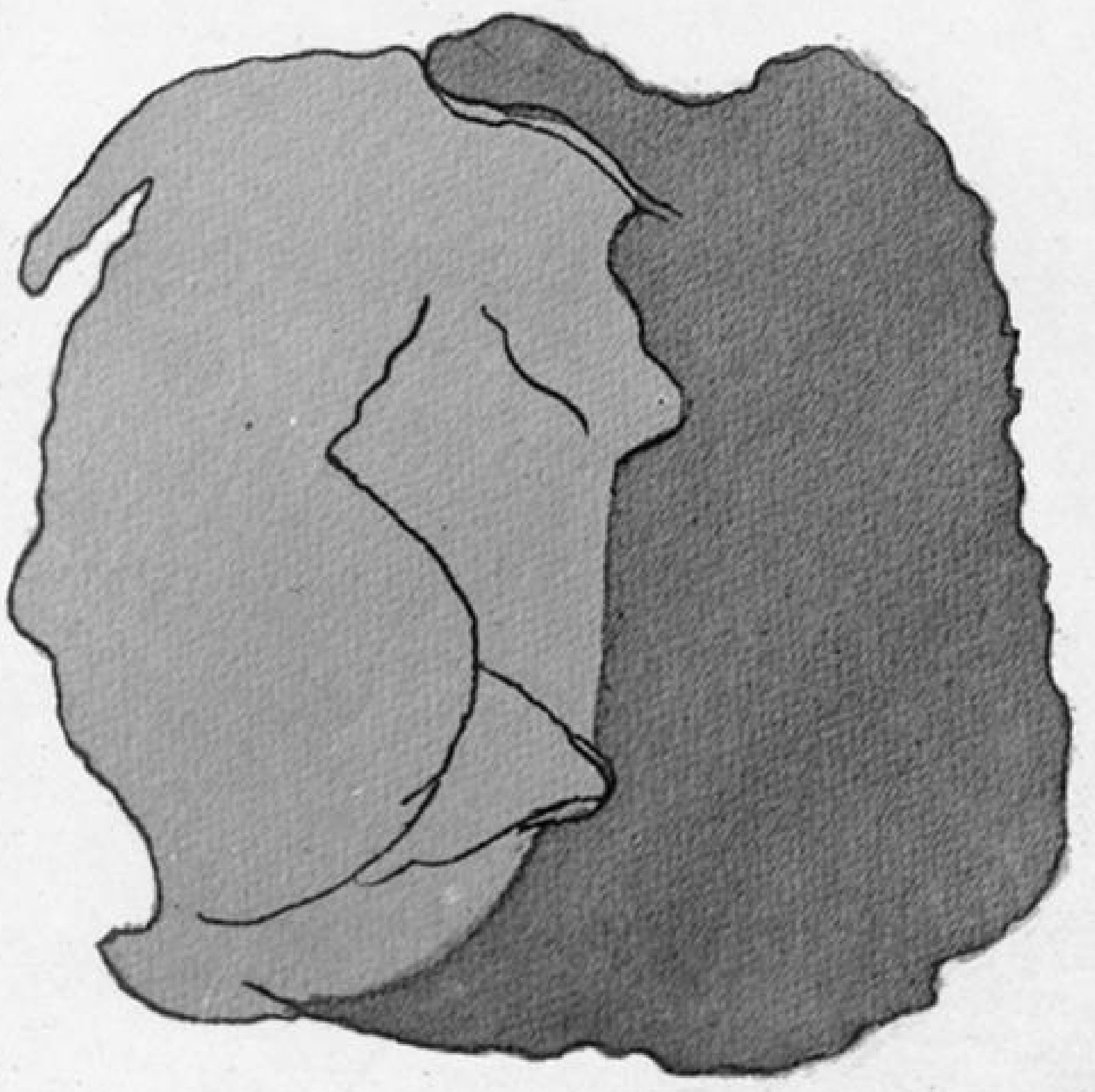

FIG. 4.

PLATE 3. (Photographs 24-27.)

24.—5th lumbar segment.

25.—Sacral segment.

26.—Coccygeal segment.

Photos. 25 and 26 show well the degeneration in the antero-lateral region and the pyramidal tract. These sections were stained by a new method devised by Professor SCHÄFER, especially valuable for photographic reproduction, hence the degeneration is better shown than in the other sections below the lesion although much more remote.

27.—The brain and portion of cortex removed therefrom in Case VII.

Figs. 2, 3, 4 are tracings of the photos. of lesions shown in Plate 1.

2 corresponds to 9, Plate 1, Case IV.

3 ,, 8, ,, Case V.

4 ,, 10, ,, Case IX.

The dark portion represents the area of absolute destruction.