THE SENSORY MOTOR FUNCTIONS OF THE CENTRAL CONVOLUTIONS OF THE CEREBRAL CORTEX. By F. W. MOTT, M.D., F.R.C.P., *Lecturer on Physiology Charing Cross Hospital Medical School.* (Pl. XII.)

IT has long been a matter of dispute among physiologists and neurologists, whether the central region of the cerebral cortex should be considered primarily sensory, sensori motor, or purely motor. In this country it has been considered by many eminent experimentalists to be purely motor and Dr Ferrier[1] still holds this view. "As there is no evidence of impairment of the common sensibility of the limb from destruction of the cortical motor zone, but conclusive evidence to the contrary, so are the views of Hitzig and Nothnagel respecting the abolition of the muscular sense equally without foundation." This is the *purely motor theory*, which was generally accepted in England owing mainly to the experimental work of Ferrier, Schäfer and Horsley, but on the continent and in America from the first it never found favour with the majority of neurologists, psychologists or physiologists. Dr Bastian however never (from a psychological stand-point) admitted the truth of this doctrine and in 1886 read a very logical paper before the Neurological Society on the "Muscular sense" its Nature and Cortical Localization, and I consider it was this strong protest of Dr Bastian against the purely motor doctrine of Ferrier, which has caused certain eminent neurologists of this country to modify their opinion. I shall now state briefly the views which are held by the various authorities.

I. *Experimental.*

Hitzig[2]. The excitable area is the seat of muscular perception and of motor ideation, viz. muscular sense. Motor troubles are associated with anæsthetic troubles but are independent of the latter: Sir Charles

[1] *Functions of the Brain*, p. 380.

[2] "Ueber den heutigen Stand der Frage v. d. localis, im Grosshirn." *Volkmann's Sammlung.* Leipzig, 1877.

Bell[1] first described this sense "as a compound function from the sensibility of the proper organ of touch being combined with the consciousness of the motion of the arm, hand and fingers. It is the motion of the fingers that is especially necessary to the sense of touch."

Bastian terms this complex combination of sensations resulting from movements, *kinæsthetic*[2] impressions. Wundt[3] says: Les sensations du mouvement, comme nous avons montré précédemment, sont pour nous des produits fusionnés complexes provenant de sensations d'origine différente."

Dr Hughling Jackson speaks of motor centres, "not however believing that these so-called motor centres are purely motor[4]."

Munk[5] in his latest work "Ueber die Fühlsphaeren der Grosshirnrinde" states that "In the cortex of the parietal lobe, specific sensations, perceptions and representations of the tactile sense occur and the associated potential memory pictures are situate." "In der Rinde des Scheitellappens die specifischen Empfindungen, Wahrnehmungen und Vorstellungen des Gefühlsinnes zustandekommen, und die zugehörigen potentiellen Erinnerungsbilder ihren Sitz haben." The paralysis resulting from lesions of the motor area Munk ascribes to the loss of the memory of the images of general sensibility and movement. To produce complete anæsthesia, the entire central region of the brain cortex must be removed.

Waller[6] holds that Munk, Bastian and Hitzig have one and the same conception differently expressed. But the motor ideation of Hitzig and Bastian is the result of muscle sense or kinæsthetic impressions; whereas Munk associates the motor area definitely with the tactile sense as well as the muscle sense, thus combining the views of Schiff and Hitzig.

Tripier[7] "Revue Mensuelle de Médecine 1880—81" extirpated various areas of the cortex and he affirms the existence of sensory centres on the so-called motor area. He finds that the sensory area for a definite limb coincides with, but is more extensive than, the motor area for the same limb. At the same time that Tripier was working in France, Mœlli in Berlin was investigating the same subject. His

[1] *The hand, its Mechanism and Vital Endowments.*

[2] *loc. cit.*

[3] *Élém. de Psychologie physiol.* Trad. Française, 1886, I. p. 421.

[4] "On Convulsive Seizures." Lumleian Lectures. *B. M. J.* Vol. I. 1890.

[5] *Sitzungsberichte der Königlich Preussischen Akad. der Wissenschaft.* Berlin, 1892.

[6] Waller. "Sense of Effort." *Brain*, 1892.

[7] Allen Starr. "The Sensory Tract." *Journal of Nervous and Mental Disease*, Vol. XI.

results were published in Virchow's *Archiv*, Bd. LXXVI. and coincide with those of Munk and Tripier.

Luciani and Seppili[1] conclude from their experiments that the central region is not only motor but sensory. They found touch most profoundly affected—sometimes completely lost. Pain and heat sensations were sometimes affected for the first few days after operation. Muscle sense constantly disordered.

Ferrier[2], Horsley[3] and Schäfer were of opinion from numerous experiments on monkeys that the central region of the cortex is purely motor. The evidence they adduced at the time was certainly very strongly in favour of this view, moreover these three observers located tactile and painful sensibility elsewhere, Hippocampal gyrus, Ferrier; gyrus fornicatus, Horsley and Schäfer; limbic lobe, Ferrier. Prof. Horsley[4] has, owing to clinical experience and a full consideration of the facts and arguments advanced by other thinkers and workers in this subject fully admitted that impressions of touch and common sensibility are registered in the rolandic area, *i.e.* that the region is sensori motor. Prof. Schäfer also admits that this region receives afferent impressions and is not purely motor.

Schiff[5] holds exactly the contrary opinion to Ferrier; for him the central convolutions are purely tactile sensory. He holds that the movements on irritation are simple reflexes, and paralysis results from the loss of tactile sensibility. The effects of lesion are like those of ataxy or lesion of the posterior columns.

Bechterew[6] states that he has obtained no appreciable sensory defects after superficial removal of the motor area in dogs and cats; (according to Munk he removed portions of the cortex only which responded to a weak current). On the other hand, Bechterew found marked disturbances of skin and muscle sensibility in the contra-lateral limbs, when he removed the portions of the cortex posterior and external to the motor area (Gyrus Sigmoideus of the dog and cat). To obtain sensory defects in the monkey it was necessary to remove the posterior central convolution (ascending parietal) which includes also motor-centres. He concludes that there are independent motor

[1] *Le Localiz. penz. d. Cervello.* [2] *loc. cit.*

[3] *Phil. Trans.* Vol. CXXIX. (1888), B. pp. 1—93.

[4] "On the Analysis of Voluntary Movement." *The Nineteenth Century*, June, 1891, p. 863.

[5] *Leg. d. Fis. Sperim.* Firenze, 1873. *Riv. Sp. d. Frenatria*, 1876. *Arch. f. Exp. Path.* III. pp. 171—179.

[6] W. Bechterew. *Die Leitungsbahnen im Gehirn und Rückenmark*, pp. 146—147, 1894.

and sensory centres, which lie very near to one another and often overlap to a certain extent. Bechterew concludes from experimental and clinical evidence that in the human brain sensory functions are localized in the parietal convolutions.

Goltz[1] only admits loss of perception of a general kind, but no paresis, and considers the phenomena are all due to inhibition of lower parts.

In his last paper, both hemispheres were removed in the dog in four operations, only the stump of central nuclei and peduncles left. The animal eighteen months after resists alteration of position, it would not allow the limb to sink through a trap-door when it was gradually lowered over it, presumably therefore it has muscular sense. It never steps on the back of the feet. With one leg injured, it runs equally well on three legs. It has however no memory of previous sensations, and really behaves like a reflex machine.

Unlike a dog, however, a monkey would be permanently paralysed and would lose tactile sensibility. Obviously tactile sensibility plays a much more important part in cerebral consciousness in monkeys, and we shall see that the fine movement of the hand, and to a less degree of the foot, of this animal are permanently paralysed after extensive lesions of the central regions of the cortex cerebri.

II. *Clinical Evidence and Pathological Observations.*

Nothnagel[2] first marked the disappearance of paresis after lesions of the cortex.

Cases of sensory disturbance accompanying motor paralysis from cortical lesions have been collected by Exner, Lisso, Starr, Luciani and Seppili and in 1888 Dana[3] went carefully through these cases and others which had since been published, making in all 142 cases. He also collected twenty cases of lesion of the gyrus fornicatus or hippocampus and he says "I am certain no amount of scrutiny can explain away the numerous cases in which superficial cortical lesions have caused monoplegias and monoanæsthesias. Dana cites Petrina, but vide Ferrier's criticism of these cases, p. 378, loc. cit. In fact although this is strong presumptive evidence it is not conclusive, for numbers of cases could be cited in which there was paralysis and no

[1] *Pflüger's Archiv*, XIII. XIV. XX., 1892.

[2] *Virchow's Archiv*, Band 57.

[3] "The cortical localization of the Cutaneous Sensations" by Charles L. Dana, M.A., M.D. *Journal of Nervous and Mental Diseases*, Oct. 1888.

obvious sensory disturbance *discovered.* The reliable evidence will come from the experience of surgeons who are called upon to remove portions of the brain for disease—their cases being carefully tested before and after the operation.

Prof. Horsley has now had five cases in which *large* portions of the brain in the rolandic region have been removed and the operation has been followed by sensory defects.

Two of these cases I have by the kind permission of Drs James Taylor and Ormerod, recently had the opportunity of testing and they bear out exactly the results of my experiments.

Dr Allen Starr[1] from an experience of more than thirty cases of cerebral operation, considers that it is clearly determined that the motor centres for the organs of most delicate action, viz.: hands and feet lie behind the fissure of Rolando; and he is fully convinced of the existence of centres for the reception of tactile sensation in the "motor area" of the cortex, these centres being especially located behind the fissure of Rolando. Dr Starr put forward this view in 1884 in an admirable monograph[2] "The Sensory Tracts in the Central Nervous System."

Prof. Albertoni and Dr Brigatti have lately recorded a case of removal of a tumour and portions of brain the size of a hen's egg from the "motor area" of a young girl. The patient at the time of the report had been under observation thirteen months after the operation. All the epileptic seizures had ceased, and the paralysis had diminished in the lower limb. Tactile, general, thermal and even painful sensations which before the operation were intact, have been affected in a certain measure since the operation over the whole left half of the body except the face. The authors see in this an undeniable demonstration of the relation between the psycho motor centres and the sensory cortical elements.

It must be admitted that cases have been reported in which portions of the "motor area" have been removed and in which no sensory disturbance was *discovered.* Usually the lesions have been small, sometimes the sensory tests[3] have not been applied till many days after the operation, and according to Munk's view unless a large portion is removed sensory disturbance will not be manifest. However explain as

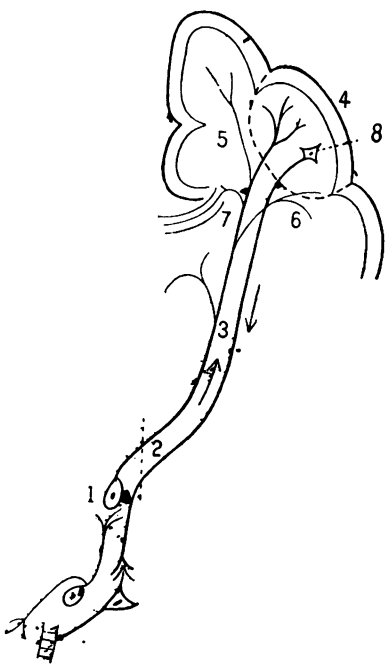
[1] *Brain Surgery.*

[2] *Journal of Nervous and Mental Diseases*, Vol. XI.; *Rivista Sperim. di Frenatria*, Vol. XIX. fasc. I. 1893.

[3] Hale White. *Brit. Med. Journal*, July 25th.

we may, the fact still remains that motor paralysis is greatly in excess of the sensory disturbance in many clinical cases. This may be explained by comparing the expansion of the centrifugal and centripetal fibres of the internal capsule to two funnels, the fibres as they lie in the internal capsule forming the tubes and expanding above like cones, the bases of each of which are nearly coincident although the tubes are not. There is this important difference however: the base of the efferent cone is made up of axis cylinder processes (neurons) just after leaving the cells from which they grow, (that is comparing a neuron to a tree, the

Diagrammatic representation of the course of the sensory impressions from a nerve cell showing concentration at one point but representation by collaterals at all parts of the "motor area."



Dotted line lesion shows complete destruction of motor elements, but possible restoration by collaterals of sensory functions.

1 Cell of Burdach's nucleus.

2 Fibre decussating to opposite interolivary layer.

3 Cortical fillet-fibre giving off collaterals to thalamus.

4 Cortical fillet-fibre ending by an arborization in arm area having previously given off collaterals 5, 6, 7.

8 Cortical motor cell with neuron.

cell and its dendrons to the roots.) The base of the efferent cone therefore consists of trunks from which all the branches and collaterals spring. The base of the sensory cone in the cortex consists only of the terminal twigs of the afferent nerve trunks after collaterals have been given off. As the afferent fibres to the cortex form an arborization before terminating in the grey matter, it is conceivable that a small portion of grey matter of the area connected with tactile perceptions will suffice to restore the sensory function, but removal of the base of the efferent cone prevents any voluntary motor impulse starting.

Other clinical evidence.

Ransom[1] and Dana[2] have faradised the human cerebral cortex without any anæsthetic and they have shown that the immediate effect was a tingling sensation in the part which would contract. This is in accord with the experience of clinicians who have studied the sensory aura in Jacksonian Epilepsy.

Dr Gowers[3] states, "the central convolutions have some sensory functions as well as a motor function. This view is supported by the fact that there is often slight blunting of sensibility on a limb paralysed by disease in this region and that in convulsions due to irritating lesions in this situation a sensory aura precedes the motor spasm. It is quite possible that the sensory region extends also to the mesial surface of the hemisphere just as does the motor region. But all the facts are opposed to the inference drawn by Ferrier from experiments upon animals that any part of the mesial surface has an exclusive or even preponderating relation to cutaneous sensibility." One reason why we have so little evidence of the seat of this function is that extensive compensation is possible. Thus a unilateral lesion in childhood however extensive scarcely ever causes loss of sensation.

There is therefore a considerable amount of clinical and pathological evidence already forthcoming which tends to prove that the central region of the cortex cerebri is sensory as well as motor.

III. *Anatomical Evidence.*

It is generally admitted that no one nerve-fibre can be traced from a point on the surface to a point in the brain. It is admitted that all

[1] "A case illustrating Kinæsthesis" by Wm. Ransom, M.A., M.D. *Brain*, LIV.

[2] "An experimental study of the seat of Cutaneous Sensations" by Charles L. Dana, M.D. *Medical Record*, May 13, 1893.

[3] *Diseases of the Nervous System.*

afferent impressions pass by the posterior roots into the grey matter or into the posterior columns, and that some of these fibres pass up only a short distance before terminating in an arborization around a cell, while others pass up in the posterior columns as high as the nucleus of Goll and Burdach in the medulla before terminating in an arborization. It is admitted that the fibres of Goll do not decussate, and experiment has shown that the other fibres of the posterior column do not in the main decussate. These columns convey afferent impressions connected with the muscular sense and very possibly touch. The impulses which travel up these columns decussate in the sensory decussations of the medulla, that is after they have passed through the posterior column nuclei. It has been shown by the embryological researches of Flechsig[1], that fibres pass from the posterior column nuclei to form the internal arciform fibres which decussate at the median raphe forming the interolivary layer and these eventually pass into the fillet. The fibres of the fillet enter the posterior part of the internal capsule and spread out in the cortex of the central convolutions behind the fissure of Rolando. This view of Flechsig has received confirmation from the experimental researches of Von Monakow[2] by Gudden's method. He observed descending degeneration of the fillet following destruction of the "motor area" in new born kittens. "Hösel[3] has lately described a case of Porrencephalon in a person who was affected in early infancy (3 weeks) and who lived to middle age. The brain showed atrophy of the central convolutions and a very marked atrophy of the fibres of the fillet. This atrophy could be traced into the opposite interolivary layer, and the internal arciform fibres. There was moreover a disappearance of the cells forming the nuclei of Goll, Burdach and the sensory and ascending 5th (to some extent) of the side opposite to the lesion. Mahaim[4] criticizes Hösel's observations, but Hösel maintains his position.

There is therefore considerable valuable anatomical evidence to show that the central convolutions receive afferent impressions, which have travelled from the periphery to the posterior columns of the cord, viz. the portions which are affected in locomotor ataxy.

[1] Flechsig. "Ueber die Verbindungen der Hinterstränge mit dem Gehirn." *Neurol. Centralblatt*, v. 1885.

[2] Von Monakow. "Zur Kenntniss der Psy. und Schleife." *Neurol. Centralblatt*, III. 1885.

[3] Hösel. *Archiv für Psychiatrie und Nervenkrankheiten.* Band XXIV. XXV. *Neurol. Centralb.* 1893. No. XVII. p. 576. Rindenschleif von Dr Hösel.

[4] Mahaim. *Archiv für Psychiat.* Vol. XXV.

Before considering my own experiments I would venture to criticize the opinion of Dr Ferrier that the Hippocampal gyrus is connected with cutaneous sensibility. Researches in comparative anatomy show that this region is connected with the sense of smell. Zuckerkandl and Broca[1] are of opinion from comparative anatomical studies that the whole limbic lobe is connected with smell. Luciani and Fasola were unable to confirm the result of Ferrier on the Hippocampal gyrus. Hill[2] has shown that it is only the Hippocampal region, *i.e.* that portion in which the border of the mantle bears fascia dentata, which is absent in anosmatic animals, and his observations in no way support the assumption of Broca and Zuckerkandl. In Nov. 1883 Prof. Ferrier[3] changed his opinion, and says: "I have all along held and hold both on experimental, and on clinical grounds, that the centres of common sensation, including muscular sensibility are anatomically distinct from those of motion and are situated in the subcortical region." After, however, the experiments of Horsley and Schäfer[4] on the gyrus fornicatus, the evidence appeared so clearly to point to the limbic lobe as a seat of cutaneous sensibility, that Prof. Ferrier adopted this lobe as the seat of cutaneous sensibility. Munk[5] has repeated the experiments on the gyrus fornicatus and he states that the operation cannot be done without producing paralysis and as the result of his investigations he asserts that the limbic lobe has nothing to do with cutaneous sensibility. I can only say that I do not think the evidence adduced *proves* that the limbic lobe is the seat of cutaneous sensibility, because in other sensory regions e.g. the occipital lobes, definite regions destroyed give rise to definite defects in the field of vision as the experiments did not show any localisation and no portion of the limbic lobe was found to be connected with a definite skin area. It was necessary to destroy the whole gyrus fornicatus to produce marked sensory defects and then a hemianæsthesia was produced. This is a very serious injury and it is possible to conceive that such a disturbance of the hemisphere would produce a hemianæsthesia, or the sensory fibres as they emerge from the internal capsule might be involved to a much greater degree than the motor. The great argument that is offered against these hypotheses is the fact that there may be persistent hemianæsthesia without motor paralysis, and case 37 in Horsley and Schäfer's work

[1] *Ueber das Riechencentrum.* F. Enke, Stuttgart, 1887.
[2] "The Hippocampus" *Phil. Trans.* Vol. CLXXXIV. 1893.
[3] "Oration before the Med. Chir. Soc." *Brit. Med. Journal,* Nov. 1883.
[4] *loc. cit.* [5] *loc. cit.*

is cited. "There was no perceptible paresis produced by the operation in this monkey. The right hand was used much less than the left." They explain this by assuming the monkey was left-handed or perhaps the diminished use of the hand was due to the loss of tactile sensibility.

The report of the autopsy viz. that the lesion had destroyed part of the anterior portion of the gyrus marginalis which would undoubtedly cause paralysis of the shoulder muscles, taken with the fact that Mr France's observation showed a naked eye degeneration of the crossed pyramidal tract, leads me to believe that the correct inference was a paresis of the shoulder muscles. The report of the sensibility tested on the 10th day supports that conclusion, for we find recorded, "after this time the sensibility began slowly to improve especially in parts." Reaction is now observed on stimulating the right hand and arm below the elbow, but none from the upper arm and very little from the upper part of the trunk down to the level of the iliac crest. The right ear is still quite insensitive, but the side of the face is sensitive. The right foot is rather more sensitive than before and indeed the whole lower limb reacts (although more slowly and less markedly than on the left side) to both tactile and painful sensations[1], that is to say the motor areas which were most likely to have been damaged by the lesion (and which the examination of the brain subsequently showed had been damaged) were precisely the parts in which sensation remained greatly diminished or lost. The face retained perfect sensibility, the upper part of the arm and trunk, which corresponds to the anterior part of the marginal convolutions, suffered loss of sensibility, while the hand (which should be highly represented in any cortical centre) gave a reaction on stimulation. By reference to the diagram we could understand why this should be if we supposed that the results were due to lesion of the fibres on their way to the motor area. Moreover the permanence of the anæsthesia from lesions of the gyrus fornicatus may be accounted for by the fact that destruction of this convolution means a lesion very close to the optic thalamus—a lesion which would also divide the fibres which pass through the corpus callosum to the opposite hemisphere, and so prevent restitution by the function being carried on by the other half of the brain. I am not prepared to say that the gyrus fornicatus is *not* connected with cutaneous sensation, but I think that the evidence does not warrant us in accepting the dictum that this convolution "is largely

[1] *loc. cit.*

if not exclusively connected with tactile and common sensation in the opposite half of the body" to the exclusion of the "motor area" entirely.

Munk[1] in criticizing this work of these three observers is much more dogmatic, for he states there is neither a sensory centre in the falciform lobe of the monkey nor does sensation remain in the monkey after injury to the so-called motor area. Nothing else is correct except that after certain limited lesions of the extremities, disturbances of sensibility were not found. This holds good for the monkey as well as the dog, and is only more conspicuous in the monkey, because the regions of its extremities are much more extensive than those of the dog, so that by small extirpations of absolutely the same size in both animals, one removes a small part of the region of the extremities in the monkey but a comparatively large part in the dog.

He also states[2] that Ferrier after destroying by cauterization or similar means the cornu ammonis met with no other result but the general consequences of any injury to the hemisphere (no matter in which region it is injured), viz., vision, hearing, movement and sensibility impaired. This was also the case in Dr Ferrier's other experiments; the injury was mostly so extensive that the monkey died in a few days, and in these cases great disturbances of sensibility and movement were found, either at once or as the inflammation and the softening spread. When the injury was less extensive, the disturbances of movement and sensibility were much less pronounced and disappeared soon. The latter group of experiments Dr Ferrier considers as not successful. This proved for Dr Ferrier the presence of a centre of sensibility in the uncinate gyrus. Luciani and Fasola have in similar experiments not met with any disturbances of sensibility. Horsley and Schäfer, after the shock of the operation was over, did not find any disturbances either of movement or of sensibility; except when the injury was very extensive (as they made it on Dr Ferrier's advice) and then the disturbance was but temporary. Munk entirely confirms the results of Horsley and Schäfer that after destruction of the cortex of the gyrus fornicatus, disturbances of sensibility occur, but he declares that it is impossible to perform the operation on the gyrus fornicatus without injuring in some way the motor area. Although Horsley and Schäfer state that in some cases they performed the operation extensively without injuring other parts, they are contradicted by their own statements *of the results* (except experiment 42) and their pictures, and by the fact that there

[1] *loc. cit.* p. 44. [2] Munk. *loc. cit.* p. 40.

were disturbances of movement in every case[1]. The question is whether the disturbances of sensibility are connected with the unavoidable injuries connected with the operation? Horsley and Schäfer deny this, but a careful analysis of their experiments only serves to confirm our view, that the two kinds of disturbances are connected with each other. Observations to find out the function of the gyrus fornicatus have not so far been successful. Munk in his latest work after thus criticizing the work of Horsley, Schäfer and Ferrier concludes that there is no centre of sensibility in the lobus falciformis of the monkey, but injury to the motor area does affect sensibility; we do not know the reason why the sensory disturbances are almost imperceptible, when the injury is small. In the motor area the sensation of touch and of pressure of the corresponding extremities is perceived, and the reaction to touch and pressure takes place. Sensibility to pain also depends on the motor area, probably exclusively as long as the pain does not exceed a certain limit, so that after destruction of those regions sensibility to pain is diminished and is but imperfectly restored later on. The same region is connected with the reflex centres of the corresponding extremities, so that after destruction of that region the reflex irritability is much increased.

I will now give a summary of my own experiments and the mode of operation and results. The expenses were partially defrayed by a grant from the British Medical Association for the advancement of medicine by research.

The experiments performed were seven.—In all cases save one, very tame intelligent animals were used. Suitable animals for testing sensibility are obtained with difficulty and many animals have to be rejected because they behave indifferently to the clip and other sensory tests. The six experimented upon were chosen from a large number of animals, and I consider the results much more reliable than could be obtained from an indefinite number of wild, indifferent, or shy animals. Most of the animals obtainable are very young and these are generally useless.

Mode of operation.

The animal having been anæsthetized with chloroform or ether the side of the head was shaved and made thoroughly aseptic. A

[1] **France examined the central nervous system of 6 of Horsley's monkeys and found degeneration of the pyramidal tract in every case.**

large flap of the scalp was raised, the periosteum separated, and a piece of bone removed large enough to expose the whole of the motor area with the exception of the lower portion of the tongue and face area. The dura mater was now opened, and from this time onward only boiled saline solution was used on the wool instead of Carbolic acid solution or Perchloride of Mercury. A soft metal brain knife (such as used by Mr Horsley) bent at a measured angle so as to avoid injuring the gyrus fornicatus was passed into the rolandic region up to the falx cerebri and then carried first forwards and then backwards so as to separate a large portion of the 'motor' area, the piece of brain being left connected only by the pia mater in places and the large vessels. In this way little or no disturbance of other parts was effected as no vessels of any size were bleeding, it required no thrombosis in the vessels to arrest the hæmorrhage, and it is claimed for this method that the injury is limited strictly to the area separated, there being no secondary softening from extension of coagulation in vessels. In all cases the scalp was sewn with interrupted horse hair stitches and collodion dressing applied. In every case the antiseptics succeeded and the wound healed all along by first intention. The lesion in 3 cases was very extensive involving nearly the whole of the "motor" area sparing the face and tongue area in part.

The lesion in 3 other cases was not quite so extensive involving mainly the leg area, but the incision was carried well below sulcus *x* and outside the area, stimulation of which would produce movements of the opposite lower limb. This means a considerable sized piece of brain separated.

In one case the lesion involved the lower portion of the ascending frontal and parietal convolutions, so as to be well outside the whole of the face area.

Summary of the Results.

Paralysis and defective sensibility invariably occurred associated together on the opposite side. If the whole leg area were removed (to do this we must cut well outside the ordinary limits, for I hold that all these centres overlap[1]), there was paralysis of the opposite leg, permanent as regards the fine movements of the foot, also diminished sensibility to all forms of stimulus for some days after the operation and a

[1] Sherrington has shown that cauterization of small portions of the arm area is followed by degeneration in the pyramidal tracts in the lower portions of the cord. *Proceedings of the Physiol. Society*, July 25, 1892.

blunting of sensibility to the presence of a weak clip which lasted as long as the animals were kept alive.

If the more extensive lesion be performed, there is permanent paralysis of the fine movements of the hand and foot and paresis of the other muscles; but even in such a case there is return of coarse associated movements of hip and knee and head and neck, probably due to the action of lower centres. Such animals showed for some time after the operation defective sensibility to sensory stimuli, since only very painful pricking or heat would cause a response; and the parts that remained permanently paralysed, such as the hand and foot, never recovered tactile sensibility sufficient to show any response to a clip fixed thereon, whereas the animal would remove a clip from much less accessible parts, such as the face on the side of the paralysed arm and leg and also from the trunk—but there was always delay. In two cases Experiments III. and V. there was marked allochiria. In fact in most cases the animal seemed to show a loss of sense of position of the limb. In all cases examinations of the brain and spinal cords were made. The extent of the lesions were observed as far as possible at the autopsy, but in most cases owing to the complete cicatrization that had occurred it was quite impossible to determine the extent of the lesion until the brain had been hardened in Müller's Fluid, and sections cut which was done in all cases. The results showed that by measuring the angle of the brain knife extensive separation of large portions of the motor area could be effected with little or no *direct* or indirect injury of the gyrus fornicatus. I say indirect because my method[1] prevented vascular thrombosis and softening, and the lesion therefore was exactly limited to the area separated. By using sterile saline solution on opening the dura little or no disturbance was caused to other parts of the brain, so that the sensory troubles which passed off or ameliorated could have been due to the injury of the particular area only. The brains and spinal cords hardened in Müller's Fluid were subsequently cut in celloidin and stained by Weigert's method and by Golgi's method or previously stained by Marchi's method and then cut in celloidin. The results obtained showed a marked degeneration in the crossed pyramidal tract along the usual course, together with a scattered degeneration of the pyramidal tract on the same side as the lesion, for apparently in the monkey these direct fibres are fibres which

[1] First adopted by Prof. Schäfer in his experiments on the frontal lobe.

do not decussate[1] in the medulla. It may be they are bigeminal as suggested by Sherrington. In vertical sections of the degenerated pyramidal tracts I have seen fibres of which the axis cylinder bifurcated, vide plate XII. photomicrograph VIII. There were also (especially when the lesion was large) a small number of scattered degenerated fibres in the median direct tract. I have not observed any degeneration of the fibres in the posterior longitudinal bundle or the fillet. I have in all cases found evidence of degeneration of the fine fibrillary network above the lesion in the cortex cerebri, vide plate XII. photomicrograph III., whether stained by Marchi's method or by Weigert's method. Of course it might be argued that these are commissural connecting fibres betweeen the convolutions, but they are limited to the lesion. There existed in all cases examined by Marchi's method degenerated fibres in the corpus callosum, especially in large lesions, vide photomicrograph IV. In two cases (2 and 6) I observed when stained by Marchi's method very considerable degeneration of the fibres forming the striæ medullares of the optic thalamus, but never any degeneration in the corpus striatum. Some objections have been raised to the Marchi method of staining and if every black dot is taken for a degenerated fibre seen in cross section, the grossest fallacies may arise.

I have, however, eliminated these sources of error, first by never assuming that black dots are degenerated fibres unless I have made longitudinal sections and observed the breaking up of the myelin sheath with its axis cylinder process, vide plate XII. photomicrographs IX. and X.

When the sections of the brain at the lesion were stained by Marchi's method, the line of incision was seen to be a mass of leucocytes filled with fat stained jet black by the osmic acid; especially was this noticeable if the animal was killed within 6 weeks of the operation. In the neighbourhood of the lesion could be seen the vessels surrounded by their perivascular lymphatic sheaths with leucocytes stained black sticking to their sides, for example the photomicrograph XI. shows the appearance of the vessels in the gyrus fornicatus of Case I., but there was absolutely no evidence of degeneration of nerve fibres such as photomicrograph III. shows, which is from the same brain just

[1] Examination of sections of the medullæ showed just above the decussation no degenerated fibres in the opposite pyramid; but where the fibres begin to decussate it can be seen that the majority of degenerated fibres sweep across to the opposite lateral column, though some few pass to the lateral column of the same side.

above the lesion. This condition of things existed in all the brains examined. To show that the portion of brain which had been separated underwent but little change with the exception of its being cut off from its connections absolutely and permanently, I stained a portion of the area by Golgi's method. Photomicrograph V. shows that the large ganglion cells with its neuron and dendrons have not all died as a result of the lesion, but I think the cicatrix would prevent absolutely any regeneration of the pyramidal tract fibres and even after 6 months no evidence of such existed. Whatever restitution of function occurred was entirely due to other portions of the central nervous system taking on the function[1]—very possibly the cerebellum; for Marchi has shown that a large number of fibres pass from the cerebellum to the anterior horns of the spinal cord.

It seems probably incorrect to speak of absolute localisation such as stimulation experiments would suggest, but rather concentration.

Prof. Gotch[2] in a very interesting paper says "In the case of the spinal cord, there is abundant experimental evidence to show that a discharge of impulses from its motor side is far more easily evoked by electrical or mechanical irritation of the posterior roots or the posterior columns than by similar irritations of the grey matter. A similar condition may rule in the sensory motor region of the central cortex. Indeed it is possible that this may only be capable of responding reflexly, that is, to the stimulation of its entering afferent nerves." He makes this proposition to account for the very strong current that is required to evoke movements by stimulation of the human central cortex. This inexcitability except to strong currents was found also in experiments made by Horsley and Beevor upon the Ourang Outang's brain. Belmondo[3] has also shown that by application of 5 % cocain in normal saline solution to the cortex, it requires a very much stronger current to excite movements than if no cocain was used. On cutting away the cortex and stimulating the fibres direct, the cocain has no influence. This rather bears out Prof. Gotch's view and suggests that possibly the cells may not be excitable, only the neurons coming from

[1] Marchi. "Origine e decorso dei peduncoli cerebellari," Vol. XVII. *Rivista Sperim. di Frenatria e Medicina Legale.*

[2] "A case of Focal Epilepsy," by Rushton Parker, B.S., F.R.C.S. and Francis Gotch, M.A., F.R.S., M.R.C.S. *Brit. Med. Journ.* May 27, 1893.

[3] "Sulla modificazione dell' eccitabilità corticale indotta dalla Cocaina e sulla natura dei centri psico-motori di E. Belmondo." *Lo Sperimentale,* 1890.

them. The existence of the large cells of the third layer with which they are connected, much resembling the large anterior cornual cells of the cord in the central convolutions, alone is strong presumptive evidence of motor function, but it is contrary to reason to suppose that these are discharged spontaneously without an afferent stimulus, and I think that clinical experience, experiment, and anatomical investigation all tend to show that these cells are discharged by sensory impulses travelling up fibres which terminate in the so called "motor area" and that it is not "purely motor" but sensori motor. The terminus of the sensory paths is coincident with but not exactly (for reasons previously stated) coextensive.

The following experiments which I now give in detail support Munk's conclusion that in the "Motor area" the sensation of touch and of pressure of the corresponding extremities is perceived and reaction to touch and pressure takes place.

EXPERIMENT I. Tame Macaque Monkey which responded to sensory tests was anæsthetized and the left leg area was separated from its connection with all antiseptic precautions. Subseqently it was found that the injury had also involved the upper part of the arm area. Six hours after the operation, the animal was found sitting on the perch with its right paralysed leg hanging down, and it was noticed also that there was some degree of paralysis of right arm.

1st day after operation. The animal was tested by weak faradic current—no notice was taken of this when applied to the right foot, but it struggled and withdrew the left foot when the electrodes were applied. If the current was made stronger it gave obvious signs of feeling. It does not respond to moderate heat and cold, but if excessive, it struggles (tested by hot wire and by test tube containing ice and hot water). Whereas previous to the operation a clip placed upon the right foot immediately attracted its attention to its removal, it now takes no notice of it.

3rd day. The monkey was tested in the presence of Dr Waller who was decidedly of opinion that there was complete loss of tactile sensibility in the right foot and greatly diminished thermal and painful sensibility as compared with the left.

4th day. Flexion of right hip and knee joints observed although like spinal hemisected animals it is only after flexing the non-paralysed limbs, that the associated movement in the opposite limb occurs.

Clip test same as before. To sharp pricking with a pin it shows obvious signs of feeling on the right side. There is still however considerable diminution of sensibility to pain. Tested with faradic brush. Sometimes a strong current was applied, sometimes no current, the animal not being allowed to see what was being done. Whereas it would show facial signs of feeling the slightest touch with the hand on the non-paralysed limb, it gave no evidence of feeling or apprehending the application of the current unless it was actually passing. Showing clearly that the tactile sensation produced by the brush did not make it conscious of the possibility of a painful stimulus following, as was the case on the left non-paralysed side. My experiments also show that after large lesions sensibility to pain is diminished in the paralysed parts.

6th day. Tested the animal in presence of Mr Horsley with the same results.

At the end of five weeks the animal had recovered movement very considerably and the only paralysis which was obvious without careful examination was in the fine muscles of the right foot. Tactile sensibility still seems to be blunted, for if a weak clip be affixed gently and without the animal seeing no notice is taken of it. There was also slight delay in response to painful sensations.

Animal killed and brain examined, vide photo. of section II. Plate XII.

EXPERIMENT II. Small tame Rhœsus—similar operation of leg area, subcortical separation on the left side—results much the same; in this case, however, the incision with the brain knife was made nearer sulcus x so as to involve less of arm area. When the animal recovered it was found that only the leg was paralysed, there being little or no defect of movement in the right arm. The same tests were applied and with the same results, viz. at first diminution of sensibility to pain in the paralysed limb, which passed off, however, sooner than in Exp. I., but always a little delay in responding to the hot wire or faradic brush. To very weak clip it takes no notice when applied to the skin of the sole of the foot. The animal was kept alive three months. There was perfect restoration of movement in hip and knee joints, but the fine movements of the foot were permanently affected, and careful testing by very weak clip and the application of wool which might or might not convey a strong electric current led me to believe that tactile sensibility was impaired in the sole of the paralysed foot. Photo. I. Plate XII. shows the brain and the scar of the lesion.

EXPERIMENT III. Bilateral Lesion—Tame intelligent Rhœsus Monkey. The leg area was first destroyed on one side and later on partially on the other; the movements which had returned in the leg paralysed by the first operation were not in any way affected by the second lesion, which was partial separation of the leg area. This animal was exhibited at the Neurological, Physiological and Medical Research Societies and it showed paresis in both legs, diminution of tactile sensibility in the feet, more marked on the side in which the muscular weakness was most apparent. The animal which was very intelligent also showed a condition of allochiria, for frequently when the strong clip was placed upon the right foot it would draw up the left foot and examine it, and after several attempts would try the other foot and remove it. This was very evidently due to a loss of power of localization. It removed the clip with the greatest accuracy and precision from the trunk, from the face, and from the arm. The animal is still alive, 12 months after first operation, and shows some defect of sensibility in the foot most paralysed.

EXPERIMENT IV. Tame intelligent Rhœsus. Subcortical separation of the whole left motor area except the most inferior portion of the ascending frontal and ascending parietal convolutions, viz. the whole of the leg, trunk, head and eye and arm areas with a portion of the face area, care being taken not to injure gyrus fornicatus: vide Brain, Plate XII., photos. VI. and VII.

1st day after operation. With strong faradic current (brush and wool) does not take any notice on right hand and foot. No notice taken of strong clip fixed on the right arm or leg in any part. Animal does not respond to sharp pricking in the paralysed limbs. The head and eyes are turned towards the left and it does not see to the right side of it, because it cannot turn its head to the right.

This animal was demonstrated at meetings of the previously mentioned societies and also to Dr Bastian.

It was noticed that whereas it would not remove a clip fixed to any part of the right arm or leg, that if attached to the face on that side it would immediately take it off. The face was not paralysed. After a month it could run about, there was however considerable weakness in the right leg, and permanent paralysis of the right arm and hand and also of the fine movements of the foot. In the parts permanently paralysed although it responded to strong painful impressions yet it never removed the clip from the hand or the foot, although it would from less accessible parts of the trunk. The animal was extremely sensitive to tactile and painful sensations on the left non-paralysed side, and it was with great difficulty that a weak clip could be attached for a single moment. For if attached to the left foot it was immediately removed with the left hand, and if attached to the left hand it was immediately removed by the teeth or shaken off. This animal was kept alive six months and at the end of that time there was still permanent blunting of tactile sensibility in the hand and foot paralysed, as shown by the following note.

Tested animal for the last time, found that it removes a strong clip from all parts of the arm, trunk, leg of the paralysed side, but generally after delay, and with considerable difficulty in localization as compared with the non-paralysed side. It never takes the slightest notice however of the clip when placed upon the palm of the hand or the sole of the foot of the paralysed side.

EXPERIMENT V. Healthy Bonnet Monkey, tame and full grown.

Subcortical section of the whole of the leg and arm area including head and eye and most of the face centre of the left side. Almost the whole of the motor area was involved. Half-an-hour after operation there was deviation of head, eyes and tongue towards lesion with paralysis of left arm and left leg.

1st day after operation. The cheek pouch noticed to contain food which he had eaten the day previously and which he makes no attempt to remove with the hand. A stoned cherry placed in front of his lips is seized when it touches the left of the median line, but as soon as it gets over to the right side he makes no attempt to get it with his hand (the eyes being covered), he is apparently quite insensitive to touching on the face, touching the cornea evokes the reflex, but no conscious sensation is manifested. A clip fixed on any part of the right side is not felt, but on the left it is immediately removed with his hand or teeth if it can not be shaken off. After very sharp pricking a delayed response sometimes occurs. (? slight paralysis of orbicularis palpebrum.)

2nd day. ? Some right hemianopsy, possibly due to the head being turned towards lesion, but no deviation of the eye. When a cherry is placed to the left of the animal it takes it with the greatest precision, when placed to the right it sees the cherry but does not judge accurately the distance with the left hand and it grasps it only after several attempts. It cannot follow well a moving object towards the right, although if held steadily it can see it and will seize it. Food still collects in the right pouch and it takes no notice of a cherry when it touches the right part of the lip although it does when it touches the left. A clip fixed on the hand, foot, or ear of the right side not noticed, but on the left side it is removed without any delay. Pricking must be strong on the right side of the body to evoke any response.

4th day. Paralysis of face is passing off, still anæsthesia of arm and leg.

7th day. A weak clip fixed on any part of the face of the right side is not removed, whereas it is immediately on the left.

13th day. While the animal's attention was engaged from the front with cherries my assistant Mr Fricke tested sensation, standing in such a manner behind the animal that it did not see. Only the strongest sensory stimuli were noticed on the right side, whereas the slightest touch would be observed on the left. Frequently allochiria has been observed, the animal scratching the left foot when the right foot was stimulated.

This animal was killed at the end of the third week. It had recovered coarse movements in the lower limbs, but there was undoubtedly loss of tactile sensibility and diminution of sensibility to pain in the paralysed parts.

In none of the foregoing experiments was the gyrus fornicatus found at the autopsy to be injured to any extent. In fact this portion of the brain was almost intact in all cases, the most obvious approach to any injury was in case 1, and this I have figured.

EXPERIMENT VI. Rather wild Rhœsus.

Similar operation to the above was performed with very similar results, but the experiment was not so valuable because the tests when applied were difficult owing to the creature not being tame. However the paralysed parts were undoubtedly not so susceptible to sensory stimuli as the non-paralysed.

EXPERIMENT VII. Rhœsus fairly tame.

Separation of the whole of the lower portion of the ascending frontal and parietal convolutions a piece about the size of a shilling.

Two hours after operation the animal was found to be anæsthetic to pricking over the whole of the right side of mouth, cheek, nose and hand. The lips were everted and tested in a similar manner with the same result.

2nd day. The anæsthesia was still present but the animal responds to sharp pricking, cheek pouch full on paralysed side, a good deal of difficulty in swallowing.

3rd day. Animal was found dead with right-cheek pouch filled with food.

As Prof. Schäfer was engaged in making experiments in this direction I did not continue my observations of removal of this face area.

It should be mentioned that these sensory defects could not be due to injury of the gyrus fornicatus or the fibres going to it.

Summary of evidence in favour of Sensory Motor functions of the Central Convolutions of the Cerebral Cortex.

Anatomical. Flechsig's embryological researches show that afferent fibres from the Corona Radiata pass to the Central Convolutions behind the fissure of Rolando. Flechsig and Hösel maintain that these fibres come from the sensory nucleus of the 5th and the nuclei of the posterior column of the opposite side, by way of the internal arciform fibres, interolivary layer and fillet. According to Singer and Munzer, Mahaim and Monakow, the fillet fibres find their end station around cells in the Optic Thalamus and from this mass of grey matter fibres pass to all the regions of the cortex cerebri by the fibres of the Corona Radiata. I would incline to this view from experiments I shortly hope to publish. Flechsig and Hösel's work however undoubtedly shows that afferent channels connect the posterior column nuclei and the sensory of the 5th with the opposite Rolandic area either directly by the fillet (Hauptschleife) or indirectly by the fillet and Optic Thalamus.

My subcortical sections show a degeneration of afferent fibres above the lesion, which would fit in with the above view, as the appearances of the cortex quite agree with those obtained by injury of the posterior part of the internal capsule.

Marinesco and Mœlli[1] have shown that lesions of the Pons in which the chief fillet (Hauptschleife) was involved, have been associated with affection of the cutaneous sensibility of the opposite side of the body.

Experimental and clinical. The experimental researches of Munk, Tripier, Mœlli, Luciani and Seppili, Schiff, and my own, all point to the fact that large lesions of the so-called motor area are followed by paralysis and defective sensibility of the skin in the contralateral limbs. Goltz, who will not admit any paralysis, still allows that there is defect of sensibility, and Bechterew, who thinks there are independent motor and sensory centres, yet allows that the two may overlap. In fact Starr and Bechterew agree very closely in their views, viz. that in man sensory defects will arise when the lesion is behind the fissure of Rolando. Now this is the region in which Flechsig claims that the sensory fibres terminate, but it may be only the limit to which the fibres can be traced by existing methods. Of course reference to the diagram on p. 469 will show that when the lesion is behind the fissure of Rolando, not only will the fibres going to this area be destroyed, but also (since they run from behind forwards), the injury will destroy the fibres which terminate in the cortical area in front of the fissure of Rolando; moreover, the farther back the injury is in the central convolutions, the nearer it will be to the neck of the sensory funnel, consequently nearer to the trunks before collaterals can have arisen.

Similarly when the angular gyrus is injured hemianopsy may occur but this is due to the destruction of fibres going to the occipital lobe. On account of this it was for a long time taught in England that the angular gyrus and not the occipital lobe was the visual centre.

Clinical evidence strongly supports the localization of skin and muscle sensibility in the central convolutions; particularly have I had this impressed upon me by the examination of the two recent cases

[1] Mœlli and Marinesco. "Erkrankung in der Haube der Brücke mit Bemerkungen über den Verlauf der Bahnen der Hautsensibilität," *Archiv für Psych.* Bd. xxiv.

of removal of tumour from the motor area by Mr Horsley. Both these patients exhibited even two months after the operation loss of tactile sensibility in the skin of the paralysed parts and blunting of painful sensations and of sensations of heat and cold. A clip fixed upon the paralysed limbs was unheeded just as in the monkeys, but when fixed upon a non-paralysed part, it was immediately recognized and removed; making me certain of the reliability of this test in animals.

Should we consider this area "a Gefuhlsphaere" and adopt the view of Munk, which is really a combination of the motor ideation (muscle sense) of Hitzig and tactile ideation of Schiff, and allow that paralysis occurs as the result of inability to revive the sensory images incidental to movement or should we look upon the central convolutions as sensori-motor? This is a psychological question that I do not attempt to answer, my object having been fulfilled if I have proved that it is no longer possible to deny that the Rolandic area possesses sensory functions as well as motor.

Explanation of Photographs and Photomicrographs, Plate XII., illustrating Dr Mott's paper on the Sensory Motor Functions of the Central Convolutions of the Cortex Cerebri.

Photo I. Brain in situ after the removal of the calvarium; on the right-hand side is seen a line crossing the central convolutions and intersecting the fissure of Rolando at a right angle. This is the line of subcortical incision in Experiment II. The animal was killed three months after the operation and there was no inflammation except along the line of incision, where there was a cicatrix which extended beneath the leg area right up to the middle line of the hemisphere.

Photo II. is a section of the brain, Experiment I., stained with carmine, and at the top is seen the line of the cicatrix which has separated completely the leg area. In this photograph is seen also a line of scar tissue going down into the white substance. I purposely show this section because it was, out of a great many that were cut and mounted, the one that showed damage approaching near the Gyrus Fornicatus, yet inspection will show that this convolution and the white matter in connection with it is intact.

Photomicrograph III. Magnification 150 diameters. A small part of the cortex above the line of incision showing degeneration of the fine plexus of nerve fibres that end in the grey matter; stained by Marchi's method. Experiment I.

Photomicrograph IV. Degenerated fibres in Corpus Callosum. Experiment I. Magnification 250 diameters; stained by Marchi's method.

Photomicrograph V. A small portion of the cortex above the line of incision stained by Golgi's method, showing a healthy pyramidal nerve-cell in the area which has been separated.

Photograph VI. Brain seen in situ after removal of the left half of the calvarium. The line of the scar separating nearly the whole motor area can be seen. Experiment V.

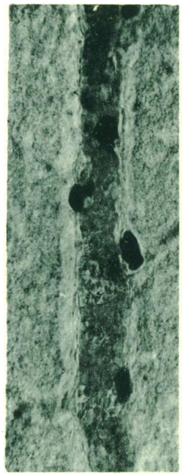
Photograph VII. is a section through the brain of Photograph VI. stained by Weigert's method. On the right side a white line somewhat like a shallow funnel is seen; this is the line of incision, which owing to atrophy of the efferent fibres of the motor area has taken this form, the apex of the funnel projecting into the internal capsule. On the left side there is a slight accidental defect in the section, but projecting down from the motor area can be seen the dark band of internal capsular fibres, which are however absent on the right side.

Photomicrograph VIII. Degenerated fibre of crossed pyramidal tract of spinal cord; apparently the axis cylinder is bifurcating. Magnification 450 diameters; stained by Marchi's method. The specimen is a vertical section of the lower dorsal spinal cord. The animal was killed ten days after a cortical lesion of the hemisphere.

Photomicrograph IX. Degenerating fibre of the direct cerebellar tract seen in vertical section, five days after a hemisection of the spinal cord. The myelin has undergone the chemical change by which it becomes black when stained by the Marchi method. The axis cylinder is visible where the myelin sheath has begun to break up. Magnification 100 diameters.

Photomicrograph X. Degenerated nerve fibre of crossed pyramidal tract in vertical section. The myelin has almost entirely disappeared. Three weeks after lesion of cortex. Magnification 500 diameters. Stained by Marchi's method.

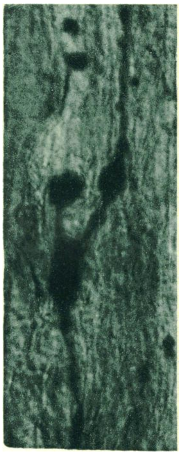
Photomicrograph XI. Vessel from the brain a considerable distance from the lesion. In the perivascular lymphatic sheath are seen numerous white corpuscles stained black owing to the Marchi fluid having blackened the contained particles of degenerated myelin which the leucocytes have picked up and are now carrying off.


Photomicrograph XI.


Photomicrograph V.


Photomicrograph X.


Photomicrograph IX.


Photomicrograph VIII.

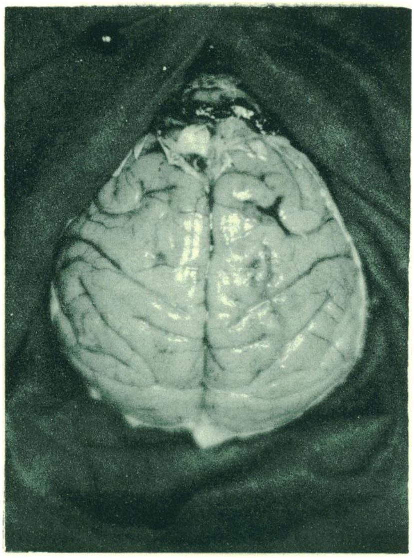


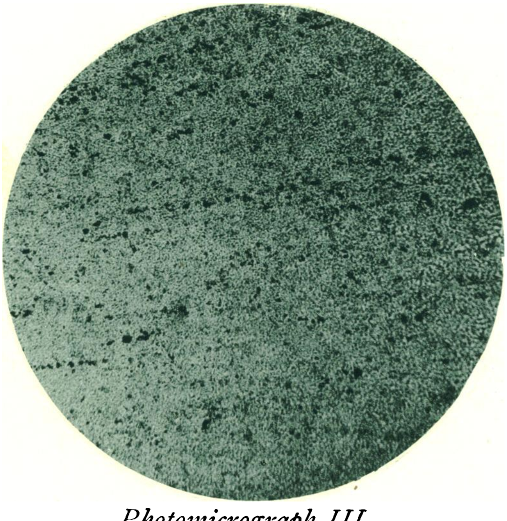
PHOTO. I.


PHOTO. VII.

Photomicrograph IV.

PHOTO. VI.

PHOTO. II.



Photomicrograph III.