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Original Articles and Clinical Cases.

AMYOTONIA CONGENITA.

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Synonyms.—Myatonia congenita (Oppenheim); Kongenitale Muskelatonie (Tobler); Maladie d'Oppenheim (Baudouin); Atonische Zustände der kindlichen Muskelatur (Bing); Congenital Hypotonia or Amyoplasia (Carey Coombs); Myopathy, infantile type (Batten).

In 1901 Oppenheim [17] first drew attention to a malady of early childhood characterised by such striking clinical peculiarities and so unlike any disease which had been previously described in its clinical aspect and progress that he felt justified in describing it as a new and separate clinical entity under the name of myatonia congenita. Since this time a number of cases have been reported, and all authorities who have written upon the subject have supported Oppenheim's claim that this disease constitutes a new and striking clinical type. The first case reported in this country was discovered by us at the National Hospital early in 1907.[1]

The patient was shown by us before the Neurological Society, and a lecture upon the subject was delivered by one of us at the National Hospital in the spring of 1907. Since then we have met with three

[1] In a personal communication Dr. Carey Coombs tells one of us that his case was in manuscript for a year before it was published (June 15, 1907).

other cases. In 1903 Dr. F. E. Batten [1] showed three patients before the Neurological Society of London which were undoubtedly cases of amyotonia congenita. He described them as cases of "Myopathy of an Infantile Type." We have included these cases in our list as they were certainly the first to which attention was drawn in this country. Our four cases have shown certain features to which attention has not hitherto been drawn, and the object of this paper is to point out these features, to call attention to Oppenheim's malady as a distinct and important clinical entity, and to put before the reader a complete account of all the cases which have been recorded up to the present time.

The essential diagnostic characters of Oppenheim's disease that will serve to distinguish it at once from all other diseases may be stated in a few words, which are here emphasized :—

"A condition of extreme flaccidity of the muscles associated with an entire loss of the deep reflexes, most marked at the time of birth and always showing a tendency to slow and progressive amelioration. There is great weakness but no absolute paralysis of any muscle. The limbs are most affected, the face is almost always exempt. The muscles are small and soft, but there is no local muscular wasting. Contractures are prone to occur in the course of time. The faradic excitability in the muscles is lowered and strong faradic stimuli are borne without complaint. No other symptoms indicative of lesions of the nervous system occur."

Under the name of congenital muscular atonia Sorgente [24] has described two cases occurring among the children of the same mother (*vide* p. 42). These cases seem to us to depart too widely from the type of Oppenheim's malady, which in all other reported cases has been so regular, to be justifiably included in this description in the present state of our knowledge. But since we have ourselves had the opportunity of observing a case of Sorgente's familial type, and since a complete pathological investigation was made by Dr. Batten, we shall here exclude these three cases from our general consideration of Oppenheim's disease, and we shall describe them in detail separately, leaving subsequent investigation to determine their position in relation to the usual type of congenital amyotonia. Our reasons for excluding these cases are the following :—

(1) The malady was familial. In Sorgente's cases two children of the same mother were affected; in our case five children of the same mother were affected.

(2) The paralysis was complete.

(3) There was complete loss of electrical excitability in the affected muscles.

(4) All the cases ended fatally within a few weeks.

(5) None of the above features have occurred in any of the cases here included as cases of Oppenheim's disease.

Our best thanks are here expressed to Dr. Beevor for his permission to make use of two patients under his care in the National Hospital; to Dr. Whait, of Hampstead, for the early notes of the patient who had been under his care for several years, and for his kindness in affording us every facility to examine and photograph his patient; and to Professor Oppenheim, who was good enough to examine one of our patients and to give us the advantage of his valuable opinion and comments upon the case.

Causation.

A careful search through the history of the recorded cases for any possible antecedents and factors in causal relation with this strange malady have thrown no light upon its etiology. Certain negative facts, however, are of considerable importance, especially in the distinction of this malady from other forms of paralysis occurring in the earliest years of childhood.

Age.—In nearly all cases the paralysis has been obvious at the time of birth or it has been noticed so few hours after birth as to make it certain that the condition has been pre-natal. This was so in eighteen out of twenty-five cases, but in four of the remaining cases it seems certain that the paralysis either appeared or became much aggravated many months after birth. These cases demand special consideration, for they form exceptions to one of the most characteristic features of this disease. In Schüller's case it is certain that the child was generally weak from birth, but it is also certain that, having learned to sit and stand at ten months of age, the child became much worse as regards weakness and atonia and lost the power of standing and sitting up. In Rosenberg's case the child seemed normal at birth: it learnt to sit up at seven months and the paralysis and flaccidity of the legs were not noticed by the parents till the child was eleven months old. In one of our cases the child seemed natural to its parents until it was nine months old, when weakness of the legs became rapidly manifest.

We are justified in agreeing with other authors that in some of these cases the condition became obvious just at the time when some attempt is usually made by parents to get a child upon its legs; that the

condition was confined to the legs and lower trunk; and that these cases were not of a severe type. It is possible that in these three patients the condition was present at birth, and that it became more obvious when attempts were made to support the weight of the body upon the legs.

We are of opinion that several writers have carried this argument too far for the purpose of reducing exceptions in attempting to make clear a new clinical entity, and we are bound upon the present evidence to emphasize a post-natal as well as a pre-natal onset for Oppenheim's disease.

In three cases the condition came on rapidly and reached its maximum within a few days of the onset of an acute illness in a previously healthy child. In one of our cases (13) an attack of acute bronchitis was followed by "complete paralysis" within a week in a child of twelve months of age, who had been up to this time apparently quite healthy. In Leclerq's case a healthy child, aged seven weeks, was seized with broncho-pneumonia and became universally paralysed within a few days, and though slow improvement had gone on all the time, four years later the case was typically one of amyotonia congenita. In Comby's case (15) the amyotonia came on rapidly following an attack of diarrhœa at four weeks, and was almost universal in its extent and severe in degree, but four months later the upper extremities and trunk had completely recovered, but a typical condition of amyotonia still remained in the lower extremities. The history of these three cases hardly admits of the explanation that we are here dealing with the effect of an acute illness in bringing into evidence an amyotonic condition already present in minor degree, but it suggests strongly that an acute toxic process was the cause of the amyotonia.

In the three other post-natal cases—(12) (Collier and Wilson), (21) (Rosenberg), and (22) (Schüller)—the onset was slow and was not preceded by any sign of general ill-health. In one case the power of observation of the mother was so limited as to make it extremely likely that the amyotonia was present at the time of birth, but there is no evidence that this was so in the cases of Schüller and Rosenberg. It seems probable that these are cases of a congenitally installed disease with a slow post-natal development of symptoms which, having lasted for a certain term, gives place to a tendency to marked amelioration.

Sex.—There seems to be a greater incidence of the disease upon males. Of twenty-five cases fourteen were males and ten were females. In the remaining case the sex is not stated.

Heredity.—The cases of Sorgente's type being excluded there is no trace of any direct or indirect heredity nor of any familial tendency in this disease, nor has any neuropathic tendency been marked in relation with it.

In the search for the causal factors of any disease present in the child at the time of birth, attention first rests upon the condition of the maternal health during the period of gestation of the afflicted child. In amyotonia congenita, acute illness, toxæmia, mental distress, debilitating influences have not been conspicuous. The pregnancies seem to have been natural in every way and to have been passed without incident. In one case the mother is said to have been weakly during her pregnancy; in another case the mother was exposed to the strain, privation, and hurried journeys entailed by residence in South Africa during the war.

In every case pregnancy continued to the full term and birth was natural. The children affected with this disease seem without exception to have been of good size and weight and of healthy general appearance at the time of birth. Miscarriages do not appear to have been prevalent from the family histories, nor is any unusual mortality to be found among the children. Signs of congenital syphilis and of rickets have not been met with in a single instance.

Onset.

In a large majority of the cases the peculiar limpness and weakness of the muscles have been noticed so soon after birth as to make it absolutely certain that the condition was present during intra-uterine life. In two cases reported by Rosenberg and Cattaneo quickening was absent during the pregnancy, whereas these mothers had noticed quickening in all their other pregnancies. This suggests the possibility that the condition may date far back in intra-uterine life. The facts that in Rosenberg's case the lower extremities only were affected (a condition insufficient of itself to account for the absence of the movements), that quickening is notoriously an irregular phenomenon, and that in severe cases the fœtal movements have been felt quite vigorously up till the time of birth, are against this suggestion. In three cases the condition was noticed not long after birth, and these may well be congenital cases in which, either from a lack of observation on the part of the parents or from a less obvious degree of the disease, attention was not sooner drawn to the abnormal condition of the children.

In four cases, those of Rosenberg, Schüller, and Collier and Wilson (12) (13), the condition did not attract attention till the ages of eleven

months, ten months, six months, and twelve months respectively. Previous writers have one and all made the attempt to drive these cases of late onset into the same clinical group in which symptoms are present at the time of birth. They argue lack of observation on the part of the parents, and that the disease, always present, becomes much more obvious when the child begins to sit up and attempts to stand; and further, in those cases where the condition has been noticed for the first time after acute illness, that the acute illness has had the effect of rendering a weakness already present much more apparent. While in one of our cases (12), in which the mother dated the onset at six months, her power of observation was so limited that she stated that the upper limbs were not affected, whereas they were most conspicuously affected; and it is quite likely that in this case the condition was present at birth, yet in the other cases it is quite certain that the children were normal for some time after birth and progressed in learning to stand and walk like other children and at a similar age. We must, then, recognize that the disease may arise in an apparently normal child at any period during the first year of life. The latest onset recorded is in one of our cases at twelve months. In three of the cases of post-natal onset the disease has immediately followed an acute illness, in two cases acute bronchitis, and in one case diarrhœa. Recognizing the post-natal onset of this disease in a minority of the cases, we consider that even in these cases we may be dealing with a disease that is congenitally installed.

Clinical Aspect.

Distribution.—The incidence of the disease upon the musculature is peculiar and forms a highly characteristic feature, which serves at once to distinguish this malady from other diseases of childhood in which smallness and weakness of the muscles are associated with atonia and loss of the deep reflexes. The affection is always strictly symmetrical upon the two sides, it may be universal in distribution, but the muscles of mastication and deglutition seem always to have escaped. When the affection is general the several parts of the body are never equally affected: the lower extremities are most often and most deeply involved, next the upper extremities, then the trunk, and lastly the face. It must be clearly understood, however, that the distribution of the affection is not in terms of the long axis of the body—face least and lower extremities most—for in one case (11), in which the face, arms and legs were severely affected, the trunk was not involved; and again in Case 20 the trunk was normal where both upper and lower extremities were much affected.

In every case the lower extremities have been involved, but in several cases (11 and 12 and others) the upper extremities have been much more severely affected than the lower extremities.

In the twenty-five cases the distribution in the several parts of the body has been as follows:—

	Involved.	Normal.	Not noted.
Face	3 ...	20 ...	2
Trunk	22 ...	3 ...	—
Upper extremities	20 ...	5 ...	—
Lower extremities... ...	25 ...	— ...	—

In the face the orbiculares palpebrarum and the retractor muscles of the angle of the mouth are the muscles chiefly involved, inability to close the eyes completely, epiphora and a blank expression of face resulting. The orbicularis oris seems never to be involved, and the same applies also to the muscles of mastication and of the tongue. All the infants with facial affection have been able to suck strongly and to swallow well. The pouting lips and furrows indicating local muscular wasting which characterize the myopathic face are never seen. The ocular muscles seem never to be affected.

In the limbs the amyotonia may be distributed equally upon both proximal and distal parts, but this is unusual. It has been stated by most of the previous writers upon this subject that the proximal muscles are always more severely affected, but it seems to us certain that this conclusion has been arrived at from the obvious disadvantage at which the proximal muscles act against gravity upon the limbs as long levers. Our experience is that in some of the cases the proximal muscles are more severely affected, as shown by their smaller size and softer feel, by their electrical reactions, and by their power of action in the most favourable position of the limb. In other cases the reverse is true, the peripheral muscles being much more affected than the proximal muscles. We are inclined to think that the major affection of the peripheral muscles is the more common event, for the peculiarities of growth attributable to the lack of the tonic traction of the muscles are only apparent in the hands and feet.

The proximal and peripheral major distribution of the affection does not alternate in the same subject; in a given case the major incidence is either all proximal or all peripheral.

It cannot be too strongly insisted that in amyotonia there is no local muscular atrophy comparable to the local atrophy which is characteristic

of all cases belonging to the group of the myopathies. The smallness of the proximal muscles of the upper extremity, for example, in a given case of amyotonia involves all the muscles from the scapulo- and humero-thoracic muscles to the elbow: all these muscles are equally small and equally weak, and the conspicuous local atrophy of the lower part of the pectoralis major, one of the earliest and most constant signs of myopathy, is never present.

The distribution of the contractures is peculiar. They have only been met with in the lower extremities and they do not correspond either in position or in degree with the severity of the amyotonia. In Cases 11 and 12, for example, contractures were very marked in the lower extremities, whereas the amyotonia was more marked in the upper extremities, and in the first of these cases contractures were present so severe as to necessitate bilateral tarsectomy, though the legs had recovered to such an extent as to permit of walking and the knee-jerks had returned.

Musculature.

The condition of the affected muscles is one of complete tonelessness with the preservation of some degree of voluntary power, though in severe cases this voluntary power may be insufficient in a proximal muscle to raise the limb against gravity. This condition has led to descriptions of complete paralysis in this disease, but careful investigation has shown that, however complete the apparent paralysis may be, yet every muscle when put into a favourable position as regards work involved contracts voluntarily. A similar condition of complete apparent flaccid paralysis in muscles which will contract voluntarily is seen in cases of chorea mollis. With the extreme limpness of the muscles is associated also considerable relaxation of the ligaments, and the most fantastic positions of the limbs and trunk may be assumed. One mother described the condition of flaccidity of her child a fortnight after birth as follows: "By whatever part of the body I held him up, all the rest of him hung down like so many pieces of yarn." The extraordinary positions into which the limbs can be placed without causing pain have in several instances first drawn the attention of the parents to something being wrong with the children. In most of the cases inability to hold the head up and to sit up have been conspicuous, and when placed in the sitting position the body becomes bunched up just as gravity and the bony parts of the body dictate. It is remarkable that no spinal deformity has occurred from this state of instability of the trunk.

The relaxation of muscles and ligaments allows of the most remarkable over-extension of the joints, and leads to a highly characteristic flail-like condition of the joints when shaken. For example, if the upper extremity of one of our cases (13) was held out at right angles to the body (the observer's hand grasping the upper arm below the insertion of the deltoid), the elbow-joint formed an angle backwards of about 145 degrees, and if the arm thus held was gently shaken the bony surfaces of the elbow-joint knocked together audibly, and if the forearm was held the wrist and fingers could be shaken like a many-tailed whip. The wrist and fingers can often be over-extended so as to come into complete contact with the back of the forearm. A capacity for extreme hyper-extension of the ankle-joint has been a marked feature of many of the cases, and in several, including one of ours, the position which the foot assumed at rest was with the whole length of the dorsum of the foot lying along the front of the tibia. In this place may be mentioned also the tendency for the hands to be unduly long and narrow and for the feet to be most strikingly long, narrow, and pad-like: this latter feature is highly characteristic of the malady.

The muscles are small, and impart a peculiar soft velvety sensation to the touch, quite different to the feel of normal muscles on the one hand or to that of myopathic muscles on the other hand. The hard patches that are so often to be felt in the muscles of myopathy, even when there is no pseudo-hypertrophy, are never present.

Very striking and peculiar to amyotonia is the impossibility of distinguishing by the touch between the skin, the subcutaneous tissue and the underlying muscle. One can make no separation between these structures, and from the skin down to the bone there seems to be but one soft homogeneous substance.

There is no local wasting of the muscles, although, as has been already pointed out, the relatively smaller size of the proximal muscles of a limb, compared with the size of the peripheral muscles, may be conspicuous in a limb where the proximal muscles show a much higher degree of amyotonia; and conversely, where the amyotonia is more marked in the muscles of the periphery, these may be conspicuously smaller than the proximal muscles. Smallness in size of one individual muscle, or of part of a muscle, such as is so commonly met with in cases of myopathy, never occurs in amyotonia.

The general outline of the limbs, as determined by the muscles, is not altered in amyotonia, though, on account of the general smallness of the muscles, the contour of the limbs is less distinct than in the normal

subject. We wish to emphasize this fact in this place as important in the distinction of amyotonia from myopathies, for in the latter class of diseases the contour of the limbs becomes much altered from the normal by the local atrophy of individual muscles, and sometimes by the hypertrophy of others.

Fibrillation has not been observed in the affected muscles, and the effect of local mechanical stimulation is not conspicuous.

It seems that those muscles that are more closely concerned in the vital processes—muscles that are employed in sucking, swallowing and in respiration—tend to escape in amyotonia, for in all the cases in which the face has been affected it has been especially noted by the authors that sucking, mastication and swallowing were well performed, and in none of the cases has it been noted that the diaphragm or the intercostal muscles were weak. From the fatality of bronchial affections among the cases it is probable that the muscles of respiration are in some degree at fault.

The loss of power in the affected muscles varies from slight weakness, showing itself only after exertion, to complete inability to move a limb against gravity, and each degree between these extremes may be seen in the muscles of the same patient in whom the degree of amyotonia varies in different parts of the body. As a rule the loss of effective power is great. Only one of the twenty-five recorded cases—apart from Carey Coombs' case—is able to stand and walk feebly, and this result has been attained after six years careful treatment. Only a few of the patients have been able to sit up, and in the cases where the upper extremities have been affected but few have been able to make any effective use of the hands. Our cases, however, show that there is the most surprising volitional control in these useless and flaccid limbs. Provided that too much power is not required for the act or to overcome gravity, we have found that the most complicated movements can be performed quickly and with a fair degree of precision.

Attitude.—The inability to hold the head erect is conspicuous in severe cases: the head rolls round anywhere upon the circle which its attachments limit. If the little patient be placed in the sitting position the body bunches up generally when the trunk is affected. The usual attitude for the lower extremities at rest is that of slight flexion and marked external rotation at the hips, flexion at the knees—the calves being in contact with the hamstrings—and extreme dorsiflexion at the ankle, the plantar aspect of the long pad-like foot being turned upwards.

Contractures have been present in all our own cases. In two cases

they were of slight degree and in the other two cases of severe degree. They have been reported in eight of the twenty-five cases, and it seems probable to us that they have been overlooked in some of the others, though Professor Oppenheim told us that ours were the only cases that he had seen with contractures. These contractures have been noted only as occurring in the lower extremity, and the most usual form is a flexor contracture at hip and knee of moderate degree. In three cases contracture of the calf muscles is reported, and in one of these there was also contracture at the hip and knee. In our case (11) the contracture of the calf muscles had produced so much deformity of the feet that a double tarsectomy was necessary to bring the feet to a right angle.

Facial affection.—In only one case among the twenty-five reported cases has there been conspicuous affection of the face (11) (Collier and Wilson). In Carey Coombs' case it is described as possibly weak, and in Tobler's case as slightly weak. In our case there was extreme weakness of the upper facial muscles; the child never frowned when crying and never wrinkled the brows. With his strongest effort to screw up his eyes $\frac{1}{8}$ in. of the sclerotic was still visible, and there was no sign of corrugation of the orbicularis palpebrarum. The weakness of the tensor tarsi was shown by the readiness with which epiphora occurred. The face had a blank and stupid expression, which was increased by his inability to close the mouth, due to a deformity of the lower jaw which brought the back teeth in contact while the incisors were still 1 in. apart. Retractor and levator movements at the angle of the mouth were never seen even when he was crying. The orbicularis oris, however, was powerful; his lips did not hang away from his teeth, and his articulation was good. Though this facial affection had been present since birth, and had apparently not improved, yet there were none of the signs of wasting of the facial musculature that characterize the myopathic face.

Electrical reactions.—All the muscles respond to the faradic current, but a very strong current is necessary to produce a comparatively small contraction. To galvanism the muscles usually contract well and briskly; there is no slow contraction and the polar reactions are normal. A tardy response to faradism with more or less normal galvanic reaction is so characteristic of amyotonia, and so infrequent in other diseases in childhood, as almost to deserve the name "amyotonic reaction." This peculiar reaction seems to be present in some degree in all the muscles of the amyotonic patient, but it is most marked in those muscles which are most affected. A remarkable peculiarity, possibly connected with the

muscular affection, is the ease with which these little patients bear the strongest faradic stimuli. They are quite unperturbed at a strength of current that is unbearable to the ordinary person.

General Nerve Signs.

There are no signs of lack of cerebral development or of mental deterioration. Several of the children have been of precocious intelligence. No fits or other cerebral symptoms have occurred among any of the cases.

The special senses have been normal in all the reported cases.

The cranial nerves have been found normal in all cases. Strabismus has not been noticed, and the ocular muscles have been free from affection in all the cases.

Sensibility seems to be normal, and the only question is as to whether there is any defect of pain sensibility. The extraordinary indifference of these children to strong faradism has already been emphasized, and two of our patients seemed to take little or no notice of an ordinary pin-prick upon the affected limbs, though they objected strongly to severe pricks. In no case, however, has definite pain-loss been demonstrated.

The sphincters are never affected.

The superficial reflexes are always natural.

The deep reflexes are invariably lost in the regions where the amyotonia is marked. It seems highly probable that the deep reflexes are always absent in the first place, and that with improvement in condition of the muscles the deep reflex returns. Out of the twenty-five cases the knee-jerk was absent in twenty-two cases. In our case (11) the knee-jerk appeared after five years absence under constant observation, and when the patient had so far improved as to begin to walk. In Berti's case (6) the knee-jerk was present in a patient who had been regularly improving for five years. In Carey Coombs' case the knee-jerk was present in a slight case where the legs were recovering.

The wrist- and elbow-jerks were present in four cases, absent in fifteen cases, and not recorded in six cases. Of the four cases in which these reflexes were present, in one case (13) they returned after nine months treatment, great improvement in the upper limbs having occurred. In Comby's case (15) they returned under observation with rapid improvement. In Rosenberg's case the arms were not

affected, and in Spiller's case the wording of the note leaves the reader in doubt as to whether these reflexes were present or not; probably they were absent.

The general health and vitality of the subjects of amyotonia seem to be good. We have been unable to detect any abnormality in the thoracic or abdominal viscera, and the same result has been arrived at by all other writers upon the subject.

Course.

The evidence of all writers upon this subject is in unison: that all cases of amyotonia tend to spontaneous improvement, and that this improvement occurs more rapidly under appropriate treatment. In no case has the least tendency to exacerbation of the disease been observed. But the improvement is very slow; in fact so slow is it in most cases that although the first case was published seven years ago we are as yet unable to say whether complete recovery ever takes place, and from a general consideration of all the cases it seems probable that improvement never reaches the stage of complete recovery. Professor Oppenheim tells us that though he has had several cases under his observation for years which have all improved markedly, yet at present they are all far from complete recovery. The most rapid example of recovery is Comby's case (15), in which the arms and trunk rapidly and completely recovered, but improvement in the legs was slow. The most complete case of recovery after a severe affection is our case (11), in which, after seven years of careful treatment, the child has learnt to walk and can now use his hands for most purposes; but here, too, recovery is far from being complete.

The disease seems to have no tendency of itself to shorten life, but the weakness of the trunk muscles decreases the resistance to bronchial affections and increases their fatality. The bedridden condition which the more severe forms of the malady entail is inductive of intercurrent maladies, and death may thus result indirectly.

Diagnosis.

When, as in the majority of the reported cases, the symptoms of amyotonia are well marked and conspicuous within a short time of birth, the diagnosis of the malady presents no difficulty if the three characteristic symptoms of the disease—the strictly symmetrical flaccidity, the

weakness without complete paralysis and the loss of the deep reflexes—be borne in mind. There are, perhaps, only two classes of cases which bear a superficial resemblance to amyotonia, in that they may present conspicuous flaccid paralysis with loss of the deep reflexes immediately or soon after birth. The first group comprises those cases of obstetrical paralysis in which a severe injury to the spinal cord has occurred in the course of parturition. The injury is usually due to a fracture dislocation of the vertebral column in the lower cervical region, and it may, by causing a total physiological transverse lesion, produce a condition of flaccid paralysis with loss of the deep reflexes. But in such cases the paralysis below the lesion is complete and there is complete loss of sensibility, readily elicited even in the youngest infants by testing the surface of the body from below upwards with a painful stimulus; directly the line separating the non-sentient from the sentient part of the body is crossed the infant at once reacts to the painful stimulus. In such cases there is usually present some local atrophic paralysis of the arm musculature from injury either to the cervical enlargement or to the lower cervical roots.

The second group of cases which needs to be sharply distinguished from amyotonia is that of infantile acute spinal muscular atrophy of familial type. A case of this nature, in which several children of the same mother were affected, was observed by one of us throughout its clinical course, and was published by Dr. Beevor [3], with a full pathological report by Dr. Batten, the details of which are here appended. Sorgente has published two similar cases, the children of one mother, under the name of congenital muscular atonia. These cases certainly form a peculiar and striking clinical type of their own, and have in our opinion no connection with amyotonia congenita for the following reasons: all the described cases have been familial; the disease is not apparent at the time of birth, but appears somewhat acutely after birth at a period varying from a few weeks to several months. There is complete atrophic palsy of the muscles with complete loss of faradic excitability. There is complete loss of sensibility to all forms of stimulation in the region affected. All the cases have ended fatally within a short period. The most extensive pathological changes are found in the cells and columns of the spinal cord. The points that will at once serve to distinguish these cases from cases of amyotonia are the completeness of the paralysis, the entire loss of faradic excitability, and the complete loss of sensibility.

When the condition of amyotonia is not apparent at or soon after

birth, but becomes noticeable little by little as the child reaches that age when it is expected to sit up, crawl about, or attempt to stand, the disease must be distinguished from other causes of weakness in the limbs of slow onset occurring at that age. The peculiar flaccidity, and especially the absence of the deep reflexes, will serve at once to distinguish amyotonia from all such conditions. Conditions of rickety weakness of the limbs are never associated with loss of the deep reflexes unless some lesion other than the rickety state is present. The rare cases in which amyotonia follows rapidly upon an acute illness must be distinguished from anterior polio-myelitis on the one hand and from diphtherial palsy on the other hand. It may be pointed out that so far as the records go at present amyotonia has only followed upon acute bronchial disease. The strict symmetry of amyotonia upon the two sides, the absence of local muscular atrophy, the absence of any complete paralysis and the absence of the rapid narrowing down of the extent of the regions affected which follows an attack of infantile paralysis are points which should prevent the possibility of any confusion between the two diseases. Diphtherial palsy is exceedingly rare during the first year of life, which is the usual period of incidence of amyotonia. The absence of the deep reflexes, and to a certain extent the flaccidity of amyotonia, might be simulated by diphtherial palsy; but the presence of nasal regurgitation and of cardiac debility, and the history and course of the latter malady, should render impossible the making of any mistake between two maladies, which, while presenting a superficial resemblance in their clinical aspects, are essentially dissimilar.

There is, then, little difficulty in the recognition of this malady and in its separation from any other type of paralysis occurring in early infancy; but a question of great importance, and one that must be discussed at length, is whether this disease is to be considered as a variety belonging to the group of the myopathies or whether it is a clinical and pathological entity entirely separate from the myopathies. Previous writers upon the subject of amyotonia have for the most considered the myopathies in this connection only from a point of view of differential diagnosis, and have dismissed myopathy briefly as being clinically unlike amyotonia, and as a condition that was most unlikely to be confused in diagnosis with amyotonia. Dr. Batten, however, published his cases under the name of "Myopathy of an Infantile Type," and on the several occasions upon which we have shown our cases before the Neurological Section of the Royal Society of Medicine it has been argued against us that these cases should be described as a subgroup of the myopathies, and

that we are not justified in following our predecessors who have written upon this subject in separating these cases as a distinct group apart from the myopathies under the title of "amyotonia congenita." In the discussion which occurred when these cases were exhibited it was pointed out that in one of our cases (12) certain of the humero-thoracic muscles were very small, and that this feature, associated with the marked contractures in the lower extremities, placed this case close to a common type of myopathy, and further that in our case (11) the facial weakness was identical with that seen in the Landouzy-Dejerine type of myopathy, and that these two cases showed transition from the type of amyotonia to the type of myopathy. And further it was argued that the amount of improvement that was obtainable in cases of amyotonia was slight, that the tendency to progressive improvement that we have emphasized was somewhat of a false description, and that many of the cases had not improved more than do some cases of myopathy under careful treatment, the course of the two diseases being much in the same line.

Before proceeding to the discussion of this question we must in fairness state that so far as the pathological evidence derived from the two cases which have been examined goes, it is quite compatible with a condition of myopathy, though the results in the two cases were widely at variance one with another.

We hold, however, that the group of cases which has been brought together under the name of amyotonia congenita is clinically quite distinct and has not as yet been proved to be associated with the myopathies. We base our opinion upon the following facts:—

(1) The myopathies are conspicuously familial diseases, whereas no familial tendency has been recorded in amyotonia.

(2) The several types of myopathies often show familial relationship one with another, whereas no case of amyotonia has been reported in a myopathic family.

(3) A large majority of the cases of amyotonia are congenital, the condition being obvious at birth; in a minority of the cases the amyotonia has appeared acutely and has reached its most severe degree in a few days. In none of its several types is myopathy apparent at birth, nor does it ever appear acutely and reach a maximum in a few days.

(4) The characteristic muscular flaccidity of amyotonia is not present in myopathy.

(5) The local muscular wasting that is a marked feature of myopathy is not present in amyotonia.

(6) The course of myopathy is one of progressive increase of the muscular weakness, that of amyotonia is one of progressive amelioration of the symptoms.

(7) Return of the deep reflexes after their persistent absence for months or years has been recorded several times in amyotonia, and has occurred in two of our cases under our observation. Such a return of an absent deep reflex has never been recorded in myopathy.

In our opinion the foregoing facts argue conclusively that this malady is a new and distinct clinical type, but its position of relation to the myopathies can only be determined when a much larger number of clinical and pathological records are at our disposal.

Treatment.

The best results have been obtained up to the present time by careful attention to the improvement in the general condition of nutrition and by the application of those special measures which have for their object the betterment of local muscular nutrition. Regular massage to the affected regions is all-important. Passive movements against the contractures have often a rapid effect in bringing about a reduction of the contractures. In cases where the contractures are of such a degree as altogether to prevent the use of a limb which is recovering power from being used in its natural position, tenotomy and other surgical measures are of value. In one of our cases, where the contracture deformity of the feet was so great that no part of the plantar aspect could reach the ground, bilateral tarsectomy was performed, with the result that the patient learnt to walk in a few months. It is important to induce the patients to use the feeble limbs as much as possible, and in such a position as they are least encumbered by gravity. Both faradism and galvanism should in theory help to improve the muscular nutrition, and they have been used in our cases with apparent good effect. There is not in this malady the usual objection that faradism both frightens and tortures the patients. Strychnine is useful, and should be administered in small doses by the mouth and over long periods. Iron, cod-liver oil, and malt are always indicated. The especial danger to which children suffering with amyotonia are liable is that of bronchial affections, which are very apt to prove fatal on account of the general weakness of the musculature. The employment of any mechanical supports whatever to enable the child to get upon his legs is entirely to be deprecated, for the additional weight prevents that

Case.	Author.	Sex.	Age.	Symptoms noticed at	Face.	Upper extremities.	Trunk.	Lower extremities.	Contractures.	Wrist- and elbow-jerks.	Knee-jerks.	Course of the disease.
1	Batten[1]	F.	6 years	Birth	Normal	Affected	Affected	Affected	Hip and knee	Not mentioned	Absent	Died of intercurrent disease.
2	Batten	M.	7 years	Birth	Normal	Affected	Affected	Affected	Hamstrings	Not mentioned	Absent	Died of intercurrent disease.
3	Batten	M.	6 years	Soon after birth	Normal	Fair	Affected	Affected	... ...	Not mentioned	Absent.	
4	Baudouin	F.	4 months	Birth	Normal	Affected	Affected	Affected	... ...	Absent	Absent	Improved. Died from broncho-pneumonia. Autopsy.
5	Berti	M.	3 days	Birth	Normal	Affected	Affected	Affected	... ...	Absent	Absent	Improved; then lost sight of.
6	Berti	F.	5 years	Birth	Normal	Affected	Affected	Affected	.. ...	Not mentioned	Diminished	Steady improvement during five years.
7	Bing	M.	3½ years	Birth	Normal	Fair	Affected	Affected	Pes varus	Not mentioned	Absent.	
8	Carey Coombs	F.	10 years	Birth	(?) Weak	Affected	Affected	Affected	... ...	Absent	Present	Marked improvement in the legs
9	Cattaneo	F.	4 months	Birth	Normal	Affected	Affected	Affected	... ...	Absent	Absent.	
10	Collier and Wilson	M.	4¼ years	Birth	Normal	Affected	Affected	Affected	Hip and knee	Absent	Absent	Steady improvement, still continuing.
11	Collier and Wilson	M.	7 years	Soon after birth	Weak	Affected	Good	Affected	Calves and feet	Absent	Present (after five years absence)	Improved. Now able to walk.
12	Collier and Wilson	M.	5¼ years	Six months	Normal	Affected	Affected	Affected	Hip, knee and feet	Absent	Absent	Improving under observation.
13	Collier and Wilson	F.	1¾ years	Twelve months, following bronchitis	Normal	Affected	Affected	Affected	Hip and knee	Present (after treatment for nine months)	Absent	Marked improvement.
14	Comby	M.	3 years	Not stated	(?)	Affected	Affected	Affected	... ...	Absent	Absent.	
15	Comby	M.	4 months	Four weeks, following diarrhœa	Normal	Affected	Affected	Affected	... ...	Returned	Absent	Upper extremities and trunk recovered.
16	Iovane	M.	3 months	Birth	Normal	Affected	Affected	Affected	... ...	Absent	Absent	Died of broncho-pneumonia two months later.
17	Kundt	F.	1½ years	Birth	Normal	Fair	Affected	Affected	... ...	Not mentioned	Absent (one Achilles-jerk present)	General improvement. Ankle-jerks present.
18	Leclerc	F.	4 years	Seven weeks, following broncho-pneumonia	Normal	Affected	Affected	Affected	... ...	Absent	Absent	Progressive improvement.
19	Lugenbühl	F.	5 months	Birth	Normal	Affected	Affected	Affected	... ...	Absent	Absent	Marked improvement in four months.
20	Oppenheim	(?)	19 months	Soon after birth	Normal	Affected	Normal	Affected	... ...	Absent	Absent	Progressive improvement.
21	Rosenberg	M.	2½ years	Eleven months	Normal	Normal	Normal	Affected	Hamstrings	Present	Absent	Great improvement after 31 months treatment.
22	Schüller	M.	19 months	Ten months	Normal	Fair	Affected	Affected	... ...	Absent	Absent.	
23	Spiller	M.	22 months	Birth	(?)	Affected	Affected	Affected	... ...	Present	Absent	Died in hospital. Autopsy.
24	Tobler	M.	4¾ years	Birth	Weak	Affected	Affected	Affected	... ...	Absent	Absent	Improved steadily for two years.
25	Variot	F.	6 months	Birth	Normal	Affected	Affected	Affected	... ...	Absent	Absent	Died of diphtheria. No autopsy.

Died of broncho-pneumonia at six months. No autopsy.

[1] These cases were shown by Dr. Batten before the Neurological Society of London as "Three Cases of Myopathy, Infantile Type."

freedom of movement that is so essential to improvement. Splints, when used to reduce contractures, should be applied only at night.

Pathology.

The pathological changes which underlie the condition of amyotonia congenita have not been subjected to such investigation as will allow of an unequivocal statement as to their nature. Up to the present time three autopsies have been made and the results published in two of the cases only, the recent case of Variot and Devillers [27] being as yet recorded only upon the clinical side. The earlier authors, in default of any pathological results, theorized somewhat widely as to the nature of the disease, but it is only quite recently that we have had anatomical data with which to compare these theories. The first pathological account was published by Spiller [25] early in 1907, and later in that year a more complete anatomical examination of one case was made by Baudouin [2]. Marfan, at a meeting of the Société de Pédiatrie in Paris, in October, 1907, mentions that a complete pathological examination had been made upon a case of his, but in a personal communication he informs us that he referred to Baudouin's case, which was in his clinique.

Bing [7] removed and examined some muscle from his case, but he does not state from which region the muscle was removed.

The following is an abstract from Spiller's examination, containing all the important points:—

"The hypotonicity of the muscles twenty hours after death was as great as during life, and the absence of *post-mortem* rigidity was most striking. On cutting into the right calf the fat was found to be 6 mm. in thickness, there was very little muscle, and this appeared paler than normal. Hardly any perceptible muscle could be found in the sole of the left foot, and the tissue removed from this region consisted of fat with a very little muscle. A piece of the triceps brachialis was removed from the left side; this muscle was paler than normal and the overlying fat was 3 mm. in thickness. Muscles from the sole of the left foot, from the back of the trunk, and from the left calf had a hyaloid appearance, and those from the sole of the foot were striking on account of the large amount of fatty connective tissue and on account of the considerable increase in the nuclei of this connective tissue. The muscle fibres were small, and those from the sole of the left foot and from the left calf were much smaller than those from the back of the trunk. It is to be

remembered in this connection that the child had more power in the muscles of the back than in those of the lower limbs. The transverse striations of the muscle fibres were well preserved, but the longitudinal striations were not so distinct. The nerve fibres within the muscle from the sole of the foot appeared to be normal.

"The spinal cord and brain were found to be well developed, and the anterior and posterior roots were normal. The nerve cells of the anterior horns of the cervical and lumbar regions, examined by the thionin method, were found to be normal. The spinal meninges were normal. The pyramidal tracts in the cervical and lumbar regions were not degenerated, and sections of these regions, examined by the Marchi method, showed no sign of degeneration. The nerve cells of the paracentral lobules, examined by the thionin stain, seemed to be normal, but Betz's cells were not numerous in the sections examined. This did not indicate that these cells had degenerated. A nerve trunk from the upper part of the right upper limb, examined by Weigert's method and by acid-fuchsin with hæmalum, was normal. The internal popliteal nerve and a nerve from the upper part of the right upper limb, teased in a 1 per cent. solution of osmic acid, were normal."

The all-important results of Spiller's examination are: (1) The absence of any appreciable abnormality in the peripheral and central parts of the nervous system; and (2) the intensity of the muscular regression in the affected regions. Definite lesions of the thymus gland and of the hæmolymphatic system were present.

The following is an abstract from Baudouin's examination, containing all the important points:—

"The autopsy was made twenty-four hours after death, the subarachnoid space having been injected with a solution of formalin two hours after death. The muscles were sunk in fat and their colour was very pale, the subcutaneous layer being 1 cm. thick. There was difficulty in isolating the rectus femoris from the fatty sheath around it. The muscles presented extensive pathological changes, the most obvious lesion being an intense sclerosis. There were numerous thick strands of connective tissue in the muscle, the vessels of which were somewhat thickened and were surrounded by a ring of deeply staining young cells, in which there was a fair proportion of eosinophile myelocytes. Some of the muscle fibres were swollen and hypertrophied, their diameters being as much as 100 μ. Surrounding these were collections of quite small fibres averaging not more than 6 μ to 8 μ; these were specially noticeable in the triceps and ilio-psoas. The nuclei of the sarcoplasm were

increased in number and sometimes locally invaded the interior of the fibres. Transverse sections revealed many muscle spindles. In longitudinal sections the transverse striation was conspicuous by its absence, while the longitudinal striation was very well marked."

In Baudouin's opinion the lesions were those of muscular regression such as are seen in the myopathies.

"Examined by Nissl's method, the cortex of the Rolandic convolutions was normal. The oculo-motor nuclei and the motor fifth nuclei were normal upon both sides, but some of the cells of the sixth and of the twelfth nuclei were in a state of chromatolysis.

"No abnormality was discovered in the spinal cord by the methods of Pal and Marchi.

"Examined by Nissl's method, the anterior horn cells of the spinal cord were diminished in volume, compared with the cells of Clarke's column at the same level; for example, at the lower part of the eighth cervical segment. As is usual, those of the internal group were smallest, but in the external group, where the cells were larger, their diameter was not more than 25 μ, and they were fewer in number. The blood-vessels were normal, and there was no trace of neuronophagia. The same features were observed throughout the spinal cord.

"A section of the anterior and posterior third left lumbar roots showed that the former (anterior) roots were at least four or five times less than the latter (posterior) roots. Now in the normal subject the anterior root at this level is about half the size of the posterior root. In addition, the posterior root took the stain much more deeply than did the anterior root. In the anterior root also the sheaths were more widely spaced and were separated by amorphous tissue.

"Sections of the sciatic nerve stained by Weigert's method showed that the nerve was not normally coloured, the myelin sheaths being scattered and unequal in the different bundles. Sections stained with hæmatein eosin showed the axis cylinders rose coloured, and these seemed to cover the field uniformly, the conclusion being that many of the axis cylinders were not yet myelinated. There was, in addition, a slight sclerosis, the nuclei of the sheath of Schwann being slightly increased in numbers.

"The condition of the nerves, therefore, was a delay in myelinization—an arrest of development—but there was no neuritis.

"The thyroid glands were intensely sclerosed, the thyroid vesicles containing no colloid material, but being full of cells. No lymphatics were to be found. In the thymus gland a similarly advanced sclerosis was present."

The important points in Baudouin's results are:—

(1) Changes in the external group of the anterior horn cells.

(2) Smallness of the anterior roots suggesting arrest in development.

(3) Abnormality of the peripheral nerve trunks, suggesting an arrest of development of the nerve fibres.

(4) Intense sclerosis and regressive changes in the muscles.

(5) Marked sclerosis of the thyroid gland and of the thymus gland.

In the fragment of muscle that was removed from Bing's patient all that was found was a possible slight increase in the nuclei; otherwise the muscle appeared normal.

When a careful comparison of these pathological results, which seem somewhat at variance, is made, the difference between them seems to be rather one of degree of pathological change than a fundamental difference. It is quite obvious from the reports that a finer scrutiny of delicate changes was made by Baudouin than was made by Spiller. It is quite possible that the essential differences in the two results—the affection of the anterior horn-cells, of the anterior roots, and of the nerve trunks, all of which were said to be normal in Spiller's case—may be due to differences in the intensity of the disease and different methods of examination in the two cases. From the clinical report of Spiller's case we think that Bing is hardly justified in his contention that the amyotonic nature of Spiller's case is "höchst problematisch." There was no positive finding in Spiller's case, which is at variance with Baudouin's result, and as regards the condition of the muscles and of the thymus gland they are strikingly in unison.

That his pathological results should have led Baudouin to the conclusion that the sum of the anatomical changes is just such as is met with in cases of myopathy is of great interest, and is a very strong argument for those who would include amyotonia as a subclass among the myopathies. The essential pathology of the myopathies, however, is far from being well understood, and it is at least possible that the two conditions, amyotonia and myopathy, while having an essentially distinct pathology, as they have clinical aspect and course, may yet show almost identical changes in the nervous and muscular systems. While holding an open mind upon the subject, we think that the pathological evidence at present available, although suggestive, is not sufficient to decide the question of the relation of the two diseases.

The condition of arrest of development in the lower motor neurones found by Baudouin is well in accord with the congenital nature of the disease and with the presence of the symptoms at the time of birth in a

high majority of the cases. Such arrest of development fits in very well with a clinical course of gradual improvement, for in the most typical example of arrest of development of certain elements of the nervous system during intra-uterine life, cerebral diplegia of the paraplegic type (Little's disease), in which there is an arrest of development of the pyramidal neurones of the paracentral region which supply the lumbar enlargement of the spinal cord, a tendency to gradual recovery is the rule.

There is one other parallel between diplegia and amyotonia which is worthy of note, and it is that both diseases, though in a high majority of cases congenital and evident at birth, in a minority of cases make their appearance some time subsequent to birth, and may develop rapidly after acute illness.

If Baudouin's deduction that the changes he found in the anterior roots and in the nerve trunks represent a condition of arrested development is the correct one, it seems probable that amyotonia is a disease of the lower motor neurone and muscle rather than a disease confined to the muscle itself.

It has been suggested by several writers, and especially by Cattaneo, that amyotonia may be due to a congenital deficiency of some internal secretion which controls muscular tone. The physiological importance of the suprarenal glands, as regards the muscle tone, and the involvement of certain internal secretory glands, at once come to mind in this connection. While there is no evidence whatever that there is any such internal secretory disorder in amyotonia, there is very distinct evidence against this theory. In the first place the distribution of amyotonia, the arms being affected most in one case, the legs alone affected in another case, the trunk escaping completely where all four extremities were severely affected in a third case, is not the distribution that would occur from any disorder of internal secretion that must of necessity affect all the muscles of the body alike. Secondly, the tendency to improve would be very difficult to explain on the ground of a congenital deficiency of an internal secretion.

It has been suggested that a condition akin to infantile myxœdema exists in cases of amyotonia, and, as far as we are able to judge, the suggestion is based upon the occurrence of chronic œdema of the legs in one case (18). Œdema has been absent in all the cases except one, and it was absent in Baudouin's case, in which there was marked sclerosis of the thyroid gland. None of the signs of thyroid insufficiency—such as arrest of growth, mental hebetude, &c., have been present in any of the cases.

Clinical Abstract of Twenty-One Cases from the Literature, with a Detailed Account of Four New Cases.

Case 1 (Batten [1]).—Female, aged 6. She was the tenth of eleven children, the rest being healthy. Full term, breech presentation, easy birth. She was said to have been born "exactly as she is at the present time," and never to have improved at all. She was very intelligent, and talked well at 2 years of age. The body was very small for the age, and the limbs were thin and the muscles small, but there was no local wasting. The hands and feet were remarkably long and narrow. There was no absolute paralysis anywhere, but she could make no attempt to stand, and could not sit up unless placed in that position. She could feed herself, and she tried to sew and to knit. Special senses, sensibility, muscular sense and sphincters were unaffected. There was slight contracture at both knee- and hip-joints. The knee-jerks were absent.

Case 2 (Batten [1]).—Male, aged 7. He was the ninth of eleven children, the rest being unaffected. Birth was natural, and he was bottle-fed. The body was noticed to be very small at birth and the legs to be contractured. He was never able to walk. The limbs were thin, but there was no local wasting, and the hands and feet were very long. All movements could be performed, but all were weak excepting those of the face, which, however, seemed expressionless. There was marked contracture of the hamstrings. The muscles reacted to strong faradic currents. The knee-jerks were absent.

Case 3 (Batten [1]).—Male, aged 6. He was the third of a family of four children, and the others were said to be healthy. He had never been able to stand or walk; he could sit up but he could not kneel; he talked well and was quite intelligent. His body was thin and small; his means of progression was to lie on the floor and roll round and round upon his longitudinal axis. The muscular development was very small, but there was no local atrophy or hypertrophy. All movements could be performed with the arms, but he was unable to extend the legs or the thighs owing to the weakness of the quadriceps, and he could not flex the thighs. The extensors and flexors of the feet were weak, but he could make all the movements of the toes. The muscles of the back and of the abdomen were weak. The movements of the face were well performed. Only the strongest faradic current produced reaction in most of the muscles, but no response was obtained in the quadriceps or in the glutei. The knee-jerks were absent, the plantar reflexes were of the flexor type.

Case 4 (Baudouin [2]).—Female, aged four months. Family history negative. Natural birth at full term. Ever since the birth of the child its neck, trunk, arms and legs remained completely immobile. On examination, the cranial nerves were normal, except for slight internal strabismus of the right eye. Could suck, swallow, smile, or cry. Double pes varus, with a slight tendency to the equinus position. Complete flaccid paralysis of voluntary movement in trunk and limbs, with the exception of feeble movements of the fingers and toes. Absolute loss of tone in the muscles, which were very difficult to feel because of well-developed superficial tissues, especially in legs. Shallow

thoracic breathing; absence of deep reflexes and of plantar reflexes; no sphincter impairment; no alteration in sensation; no response in muscles to a strong faradic current; no sign of rickets or congenital syphilis.

Under treatment in hospital general improvement, but no change in muscular condition; child died of broncho-pneumonia a month later. The results of the pathological examination are quoted above.

Case 5 (Berti [6]).—Male, three days old. Family history negative; well developed and born naturally at full term. Flaccid paralysis of arms and legs; flaccidity of all muscles. Drawing in of sternum and lower ribs with inspiration. No loss of sensation; absence of superficial and deep reflexes; uncertain reaction to faradism in paralysed limbs; no impairment of sphincters. After three weeks, improvement in respiration, some movement of one arm in response to stimuli, and slight flexion of fingers on pricking palm of hand. Subsequent history unknown.

Case 6 (Berti [6]).—Female, aged 5. Negative family history; normal birth. From birth until child was about a year old, no voluntary movements of trunk or limbs, with exception of very slight movement in one arm and fingers; better movements of head. Gradual improvement in arms, and after about one and a half years signs of life in lower extremities. Since, steady though slow progress. At end of five years improvement rather quicker. When seen then all movements of limbs present, though feeble and slow; able to stand and to rise from the floor; unsteady on legs; muscles all very flaccid and atonic; faradic excitability reduced; cutaneous reflexes active, knee-jerks diminished, sometimes uncertain. No alteration in sensation; no sphincter trouble. Still further improvement with arsenic and strychnine.

Case 7 (Bing [7]).—Male, aged $3\frac{1}{2}$. Family history negative; normal birth. Congenital bilateral pes varus. Parents stated that since birth there had been great weakness and softness of the muscles; child could neither stand nor walk. When examined, it was seen that there was no voluntary movement of the legs, where, however, the muscles were well developed. Child could not sit up properly, nor could it hold its head up for more than a minute or two. Arms could be moved about but weakly; arm muscles very flabby. Could drag itself about on the floor by the help of its hands. Great freedom of passive movement at all joints. Knee-jerks absent. No sensory changes; no sphincter impairment. Muscles reacted to both electrical currents; response to galvanism diminished, but no reaction of degeneration.

Case 8 (Carey Coombs [11]).—Female, aged 10. Family history negative. Natural birth at full term. Within half an hour of her birth one hand was noticed to be peculiarly flabby and loose. When she began to learn to walk it was found that her legs gave way under her; when she was only $2\frac{1}{2}$ years old the fact that her calves were very small was remarked upon. Till she was 7 or 8 her ankles turned over so readily as to cause a serious disability, as she often fell. Her hands and their possibilities have always been a source of entertainment to her friends; at school this has developed to such an embarrassing degree that her parents have been obliged to forbid her "showing off" to her schoolfellows.

The orbiculares palpebrarum seemed slack and toneless, but not appreciably weak. Muscles of mastication, with those of tongue and lips, not atonic. Universal defectiveness of power accompanied by, and apparently proportionate to, a poor development of the muscles generally; distal parts of limbs seemed to have suffered more than the proximal; this weakness and poor development were evenly distributed. Muscles could be felt quite distinctly, though they were small, soft, and doughy. The impression given was different from that derived from fingering atrophied muscles. The most striking feature was the remarkable hypotonicity of the muscles; the result was an abnormal freedom of passive movement at various joints. The knuckles could be made to touch the back of the wrist, the palm of the hand could be pressed against the front of the wrist. Lower limbs also hypotonic, but not to the same degree as the arms; very distinct indications of hypotonicity in the muscles of the trunk also. Knee-jerks and Achilles-jerks were present on both sides, but the tendon reflexes of the upper extremities could not be elicited. Electrical reactions showed definite decrease of muscular excitability equally to both currents, roughly proportionate to the diminution in volume and power of the muscles. No diminution or other perversion of sensation, special or cutaneous, nothing of the nature of trophic change, apart from the muscles.

Under treatment there has been produced a definite increase in the muscular strength of the legs, though the hands do not respond. The muscles, according to the parents, have not grown flabbier since the early age at which it was discovered that something was wrong.

Case 9 (Cattaneo [8]).—Female, aged four months. Consumptive family history; natural birth. During the pregnancy mother did not experience quickening. Breast-fed at first. At birth it was noticed that the child did not move its arms or legs; father thinks it can now move its arms. Cannot hold its head up.

Well nourished, with normally developed musculature; slight kyphotic curve in cervical region; limbs immobile, presenting the appearance of a flaccid paralysis, except for slight movements of hands and feet. Cutaneous and deep reflexes were absent; no sensory change; very feeble muscle twitches, with strong electrical stimulation (both currents) in arms and legs. (In this case the existence of a scar over the lumbo-sacral region suggested a possible spina bifida occulta, but the characteristic signs of that condition were wanting.)

Case 10 (Collier and Wilson).—H. A. C., a boy, aged 4 years and 3 months, was admitted into the National Hospital on February 18, 1907. The parents were young and healthy. There was no history of syphilis, and the mother had had neither miscarriage nor stillborn children. There were three children, the eldest being a healthy girl of 7; the second was the patient, and the third was a healthy girl of eighteen months. The family history was unimportant.

The patient was born at full term, and delivery was natural. At birth he was well shaped but thin; he was breast-fed from the time of birth; he was delicate, and always had trouble with the chest; he had suffered with measles,

FIG. 1.

From Case 10, showing the long pad-like foot and the extreme dorsiflexion of the ankle.

FIG. 2.

From Case 10, showing the bunched-up attitude in sitting.

whooping-cough, varicella, bronchitis and pneumonia; he has been constantly attending hospitals since he was six weeks old. He began to talk at the usual time.

From the time of birth his mother noticed that the position which the legs assumed naturally was one of flexure at hip and knee and extreme dorsiflexion at the ankle, so that the backs of the feet touched the shins. The legs were very weak and always absolutely limp. The arms were weak and very limp. He could never hold his head erect, and the body "bunched up" when he was sitting. He had gradually improved in power ever since birth, but he could not stand for more than a second or two, and the legs would not go straight. He

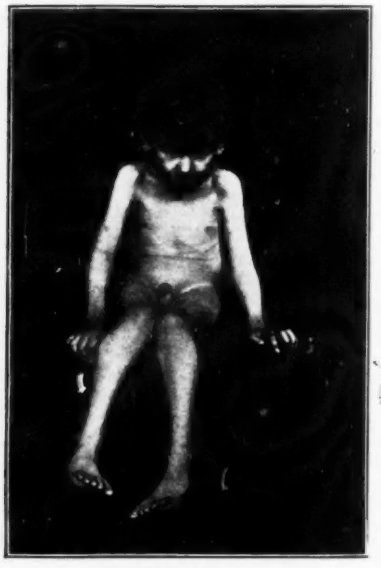

FIG. 3.

From Case 10, showing the general smallness of musculature and the long feet.

had never suffered pain, and had had no sphincter trouble. The legs were often cold and blue, and he had been much troubled with chilblains. The mother was sure he had never had any loss of sensibility in the legs; he had always been bright and intelligent.

On admission: Patient was a small, thin, and peculiarly soft, limp child, of good colour. Hair normal. The ear, palate and cranial vault were well shaped. The fontanelle was closed. The teeth were extremely carious, most of them being black, with the enamel gone and with transverse grooves. The

thoracic and abdominal viscera seemed normal, except that a slight systolic murmur was present over the whole extent of the sternum and that there were signs of slight broncho-pneumonia. The abdomen was scaphoid in shape and the waist *en taille de guêpe*, owing to the prominence of the costal margins and the laxity of the muscles of the abdominal wall.

Intelligence and attention were very good; he spoke well for his age. No giddiness nor fits had occurred. The special senses and the optic discs were normal; the cranial nerves were normal. The muscles of mastication were not powerful, neither were the facial muscles. Expression and smiling were normal.

FIG. 4.

From Case 10. A usual attitude of this patient. The difficulty of holding up the head and the extreme external rotation at the hips and dorsiflexion at the ankles are well shown.

The musculature throughout the body and limbs was small and seemed absolutely atonic, and the joint ligaments were relaxed, so that the limbs could be placed into all sorts of fantastic positions without causing any discomfort.

On palpation it was impossible anywhere to distinguish the limits between subcutaneous tissue and muscles, even when the latter were in voluntary contraction. The muscular regions had a peculiarly soft velvety feel, quite different from the feel of the limbs of a normal child. A limb held by its proximal end could be shaken like a flail.

There was marked contracture of the ilio-psoas muscles, adductors and hamstrings upon both sides, but none of the gastrocnemius. All voluntary movements of all the muscles of the body could be performed quickly and with normal range, the above-mentioned contractures being taken into account, but the power was very feeble.

There was no deformity of the body or limbs beyond the contractures. The vertebral column bowed in the sitting position, but the curve disappeared on holding the child from the shoulders. There was no webbing of fingers or toes.

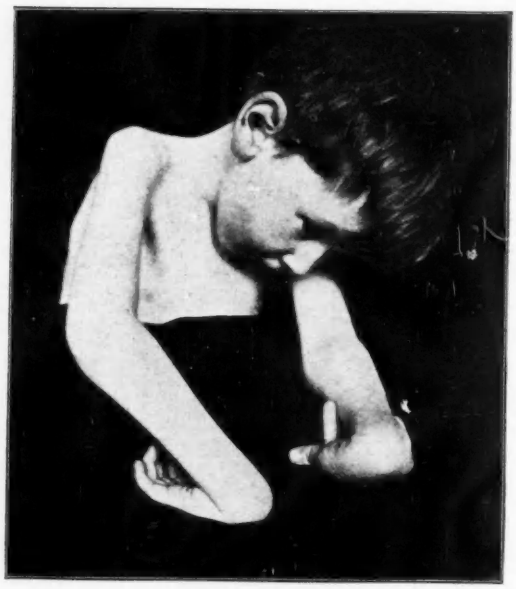

FIG. 5.

From Case 10, showing the extreme flexion possible at the wrists.

The plantar surfaces of the feet were almost flat, there being no ball to the great toe. The soles were very soft, and were like long pads, which spread out gradually on either side from the heel forwards.

The bones were small and very easily bent, the radius and ulna and the tibia and fibula of either side being easily touched together by the pressure of the observer's thumb and index finger. Skiagrams showed that the ossification of the bones of the limbs was normal for a child of the patient's age.

There appeared to be no objective sensory change, but it was most remarkable that this child exhibited no concern and complained of no pain when

strong faradic stimuli were applied to the limbs. Muscular sense and sense of position were possibly defective.

Faradic excitability was considerably lowered, strong stimuli being required to produce contraction. Galvanic excitability was slightly below normal, there being no change in the polar reaction.

The deep reflexes were absent without exception. The abdominal reflexes were present. On stimulating the soles of the feet the response seemed always to be a voluntary action, so that it was difficult to ascertain the actual nature

FIG. 6.

From Case 10, showing the adductor contracture at the hips.

of the plantar reflexes; probably they were flexor. No foot-clonus; sphincters normal.

Case 11 (Collier and Wilson).—A little boy, aged 7, was seen in consultation with Dr. Whait, of Hampstead, in May, 1907, suffering with universal weakness since birth and bilateral club-foot.

It was stated that several members of the mother's family were unable to close their eyes properly, and that the mother of the patient was very weak in her limbs when a child, but that she had perfectly recovered. She had had

three children, the patient being the eldest. The second, a girl, is said to have had something wrong with the limbs; she died at the age of 2. The third child died within a few days of birth.

The present patient was born in South Africa during the war, and the mother had been subjected to considerable hardships and privations during her pregnancy, but had no definite illness. The child was born at full term. It was noticed directly after birth that his head was large and heavy, and that he could not hold it up. Soon after it was apparent that he was unnaturally limp, and he had no strength to move except in his back, which has

FIG. 7.

From Case 11, showing the double-jointed hands.

always been the strongest part of him. He could not grasp anything with his hands until he was 3 years old. The club-foot was noticeable soon after birth, and was so marked at the age of 1 year that tenotomies were performed. He was always fairly intelligent. A photograph at the age of 3 shows that the facial peculiarities which will be subsequently described were quite as apparent then as at the present time. He was never able to walk. He improved slowly, and at the age of 3 he was brought to England, and since this time he has been continuously under the care of Dr. Whait, and

has slowly improved all the time. When Dr. Whait first saw him the head was markedly large, the facial muscles were weak, and there was inability to close the eyes completely. There was universal flaccidity and weakness, most marked in the upper extremities, where all the joints were flail-like. In the lower extremities the muscles above the knees were flaccid, but there were marked contractures of the muscles of the legs, both feet being found in a dropped and inverted position.

The muscles were small and soft, and it was impossible by palpation to distinguish between the muscle and the overlying skin and subcutaneous tissue.

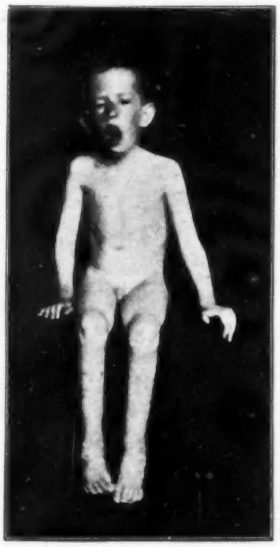

FIG. 8.

From Case 11. Maximum effort to close eyes.

Every muscle in the body contracted voluntarily, but so feebly that no useful act could be performed with the limbs.

All the muscles reacted to faradism, a much stronger stimulus than the normal being necessary to elicit contraction. It seemed that the child was able to bear faradic stimuli more easily than a normal child.

The aspect of the face was peculiar, the frontal region being unduly large, the lower face and chin being unduly small. The mouth was always open. The distance from the articular process of the mandible to the angle was so short that in closing the teeth together the posterior molar teeth came in

contact while the incisors were still ½ in. apart. This condition may have been a developmental peculiarity or it may have resulted from contracture of the masseters and pterygoids preventing the growth of the vertical process of the mandible. The triangular face, open mouth, and feebleness of the facial muscles gave the child an imbecile expression out of all relation to the very fair degree of intelligence which he possessed. All the facial muscles contracted voluntarily, but very feebly. The eyes could not be completely closed, and when crying the absence of facial contortion was most remarkable. The child spoke well, but with an articulatory defect which was obviously due to his inability to close the lips and make the front teeth meet.

The special senses were normal; there was no strabismus or nystagmus.

Sensibility was natural, with the reservation that strong faradic stimulation seemed to be very easily borne. There was no sphincter trouble.

The superficial reflexes were normal. The deep reflexes were entirely absent.

The child was circumcized by Dr. Whait, and it was found that he was hæmophilic; the bleeding was not arrested for many days.

From this time up to the present there has been very slow but regular improvement, and now the child can make effectual use of his hands. He cannot stand yet and, the deformity of the feet standing much in the way in this respect, a double tarsectomy has recently been performed.

In the early part of the present year (1907) it was noticed that for the first time a feeble knee-jerk could be obtained upon both sides. At present the knee-jerks are easily obtained, but all other deep reflexes are still absent.

When again examined in March, 1908, this patient had made good further progress, and could walk a little without support.

Case 12 (Collier and Wilson).—S. A. I., a little boy, aged 5¼, was brought to the National Hospital in February, 1907. His mother stated that he had been backward since birth, that he was very clumsy with his hands, and that he was unable to use his legs.

The parents were healthy, and there was no history of any family disease, except that the mother's aunt was said to have had epilepsy. There were seven children, of which the patient was the fifth. Two of these had died in early infancy, one aged 11 months of blood poisoning, and one aged 7 months of whooping-cough and convulsions. The other children were healthy. The mother had had good health during the pregnancy, and birth was natural and easy. The child was breast fed till 15 months old. The mother, who was not at all an observant woman, said that she had not noticed anything wrong with the child during the first six months, though she had remarked that he could put his limbs into extraordinary positions quite unlike her other children. After this time she began to notice that his legs were weak. He was late at attempting to stand, and never accomplished anything more than standing up when holding on to anything. He could never walk alone. This ability to stand when supported lasted only two months, after which he gradually became weaker and weaker on the legs. That the mother had never noticed anything wrong with the upper extremities, even up to the time when the

child came under our care, is a good proof of her extreme lack of observation, for the affection of the arms was most noticeable.

On admission, he was a pale, thin, starved-looking child of average height. His intelligence was unusually good for his age. He had never had fits. The special senses and the cranial nerves were normal. The facial musculature was well developed and symmetrical, and the facial movements were good; there was no difficulty in speaking or swallowing, and the tongue, which was protruded straight, was normal in size and was not tremulous.

All the muscles of the upper extremities were below the normal size, but all voluntary movements could be performed with normal range and fair power. There was most absolute hypotonia of all the muscles with marked relaxation of all the ligaments, so that all the joints were more or less flail-like. The upper extremities could be folded behind the back and could be put into many extraordinary positions without causing the least pain.

The muscles of the neck and of the trunk were thin and weak. He could only just raise the head from the bed when lying in the supine position, and sat up with difficulty, the body being bunched up, with a tendency to kyphosis.

The muscles of the lower extremities were flabby, but they had a firmer feel to the touch than had the muscles of the upper extremity. There was slight contracture of the flexors of the thighs and of the hamstrings, and a more decided contracture of the muscles of the feet, giving rise to a considerable degree of pes cavus. All voluntary movements were possible and were of fairly good range, except in so far as they were hindered by the contractures, and the power was fair; but the extensors were weaker than the flexors at all joints. The excitability of the muscles to faradism was markedly diminished, and the child showed no signs of pain when strong faradism was applied. The reaction to galvanism was normal, sensibility was normal, and there was no affection of the sphincters. The superficial reflexes were normal. The deep reflexes were entirely absent. This patient is improving markedly in power under treatment.

Case 13 (Collier and Wilson).—M. S., a girl, aged 1 year and 8 months, was admitted into the National Hospital, under the care of Dr. Beevor, in September, 1907, suffering from loss of power in both legs.

Both parents were healthy, and there was no history that any member of the family had been similarly affected. This little girl was the only child of her mother, who had enjoyed the best of health during her pregnancy and had felt normal fœtal movements. She was born at full term and was breast fed for ten months; she was quite well and thriving till she was twelve months old, when she had already cut six teeth. At this time she was seized with an attack of bronchitis, and was ill for a month. She had no rash and was not feverish, but at the end of this illness it was noticed that she could not move the legs at all. The arms were said not to have been affected. For the next six months there was absolutely no power of movement in the legs, but in the subsequent two months which preceded admission she began to move the legs and the power in them gradually increased.

On admission she was fairly developed for her age, but she was thin and somewhat pot-bellied. The special senses and the cranial nerves were normal, and her intelligence was fair. The movements of the face were strongly performed. There was fair power in the neck and trunk. All movements of the upper extremities were performed, and with fair power; but the arms were very flaccid, and movements in all directions were much more free than is normal. There was hyperextension at both elbows, and if with the arm held in the observer's hand the forearm was allowed to fall back passively into the position of extension, the olecranon came in contact with the humerus with an audible tap, well demonstrating the condition of flaccidity of the muscles. Both lower extremities were in a condition of severe flaccid palsy; they could be placed in the most unnatural positions without pain, and

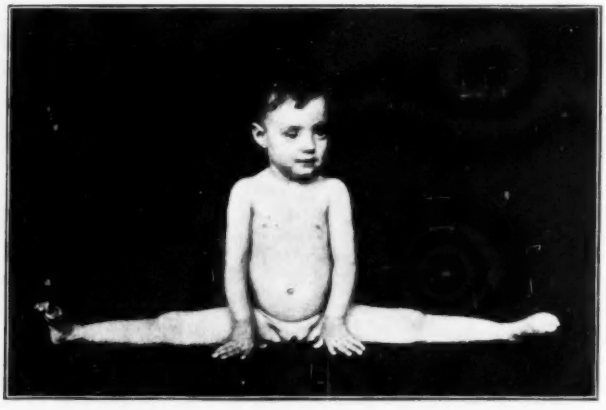

FIG. 9.

From Case 13. Usual attitude. The affection is of the lower extremities mainly.

they remained in any position in which they were placed. Both feet could be dorsiflexed with ease to the extent that the whole length of the dorsum of the foot was in contact with the tibia. The usual position that the limbs assumed was one of slight flexion with extreme external rotation at the hips, knees slightly flexed, the feet everted, and the toes pointed.

In the lower extremities the musculature was absolutely atonic. The limbs had a peculiar soft velvety feel, the skin, subcutaneous tissue, and underlying muscle being quite indistinguishable to the touch. All the movements of both lower extremities were very weak and could be resisted with great ease. Nevertheless, the voluntary control which the child had over them was very considerable. She could flex and extend all the joints without exception, and

she could abduct and adduct the thighs. There was slight flexor contracture at the hips, and to a less extent also at the knee-joints.

There was absolutely no trace of any local muscular wasting throughout the body—the lower part of the pectoralis major and the posterior axillary muscles were as well developed as the other muscles of the limbs. Very striking indeed was the extreme flaccidity of the hands and feet, which, when shaken passively, performed loose, flail-like movements in all directions.

Sensibility to touch was normal everywhere; but upon the limbs the child did not seem to take due notice of a slight prick, though a severe prick at once produced the usual signs of pain. It was very obvious that she bore the strong faradic stimuli necessary to obtain contraction in the muscles with much greater equanimity than does a normal child. The deep reflexes were everywhere absent. The plantar reflexes were of the flexor type.

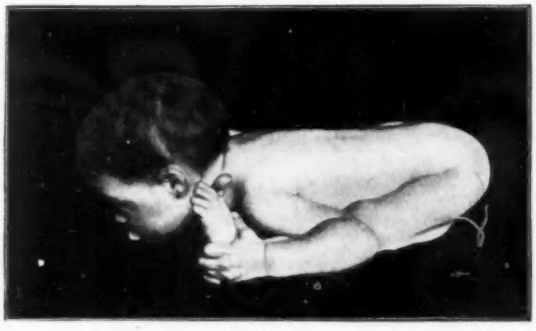

FIG. 10.
From Case 13. A characteristic attitude.

The electrical excitability of the muscles to faradism was everywhere present, but a powerful stimulus was necessary to produce a small twitch. All the muscles responded to galvanism with a normal polar reaction, and without any slow contraction.

After this patient had been in hospital for three months under regular massage, tonic treatment and good feeding, very marked improvement in the power of all the muscles was noticeable. The wrist- and elbow-jerks returned and were readily obtainable, but the knee-jerks are still absent.

Case 14 (Comby [9]).—Male, aged 8. When seen first in September, 1905, he could neither walk nor stand, and when he sat up his spinal column showed a pronounced kyphosis. The child was well fed, had put on weight regularly, and revealed no trace of rickets.

An intelligent little boy, the only defect he presented was in his muscles, which were everywhere soft, but not atrophic. He could move his legs in bed,

but they were not strong enough to support him. All deep reflexes were absent. Sensation normal.

Case 15 (Comby [10]).—Male, aged 4 months. At the age of one month he had an attack of diarrhœa, and the next day there was noticed a general paralysis of the infant's muscles; it could neither hold its head up nor move its limbs. After eight days considerable improvement, the legs alone remained paralysed.

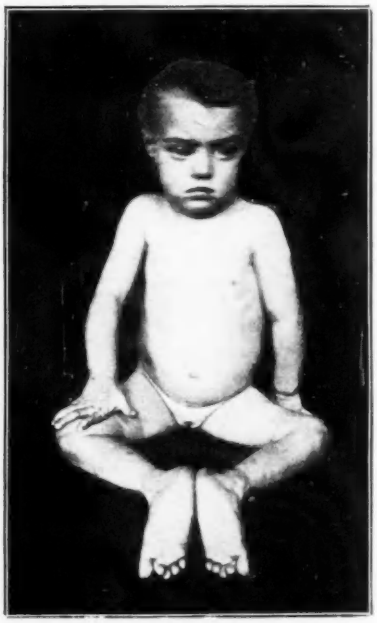

FIG. 11.

From Case 13. Usual attitude. The affection is of the lower extremities.

On examination the latter were immobile; no appreciable muscular wasting anywhere; sensation normal; knee-jerks absent. The head rolled from side to side. When the child cried, the abdominal wall bulged on the right side; dorsal kypho-scoliosis. Electrical examination showed a hypo-excitability of the back of the right thigh and of the right calf; no reaction of degeneration. This result did not correspond with the general muscular inertia of the child.

When seen eleven months later the child looked quite well, but the muscular atonia persisted.

Case 16 (Iovane [12]).—Male, aged 3 months. Family history negative. Normal pregnancy; natural birth at full term. The child appeared perfectly

healthy and was able to take the breast, but it was noticed on the first day that there was no voluntary movement of arms or legs, and that head rolled about on trunk. Seen three months later, child appeared in excellent health. No atrophy of muscles; face unaffected; no difficulty in swallowing; sphincters normal. Flaccid paralysis, with absolute atonia of muscles of arms and legs; feeble movements of distal segments of arms. Muscles of trunk as atonic as those of limbs. Shallow thoracic breathing. No alteration in sensation; deep reflexes absent; plantars absent, but abdominal reflexes present. Practically no response to galvanic stimulation of muscles, slight to faradism. Child died two months later of broncho-pneumonia.

Case 17 (Kundt [13]).—Female, aged 18 months. Negative family history. Natural birth at full term. During the pregnancy the mother noticed quickening just as with her other children. Bottle fed. At first no movements of the legs at all; after six months the child began to move its feet and ankles. Gradual improvement, but still unable to stand or walk. When seen could sit up, and arms seemed all right. Well developed and nourished when first under observation. Absolute hypotonia and soft flabby feeling of the muscles of the legs, but their temperature and colour were normal. Great laxity at all the leg joints. Active spontaneous movements only in toes, feet, and rarely of lower leg. Painful stimuli, however, made the child move its legs at knee and hip, not so well on right as on left side. Knee-jerks absent on both sides, left Achillis-jerk present. No muscular response to mechanical stimuli. Muscles of leg reacted fairly to both forms of electric current, with the exception of the right tibialis anticus. Above the knee, however, there was practically no response except a slight one in the hamstrings and the left adductor group. No reaction of degeneration. Cranial nerves, special sense organs, and intelligence normal. Radiographs of the bones showed a normal condition.

Some general improvement in the muscles of the legs with four months electrical treatment. Improvement in the Achillis-jerks.

Case 18 (Leclerc [14]).—Female, aged 4. The parents were healthy. The mother had had four pregnancies; the first ended in a miscarriage at the second month, the second child was stillborn at eight months, the third child was born weakly at full term and died at the age of two months, the last child was the patient. During the pregnancy the mother was well in health and felt normal fœtal movements. The child was born twenty days before term and the birth was natural. She appeared quite normal at birth and for the following seven weeks, when she was seized with broncho-pneumonia. A few days subsequently she developed a universal flaccid paralysis, the face and muscles of deglutition escaping. From this time onwards she improved slowly but progressively. At the age of 4 her condition was as follows: There was extreme flaccidity in all four limbs, with relaxation of all the ligaments and flail joints. Every muscle could be moved voluntarily, but the power was so feeble that no effective movement could be made; she was, however, able to hold the head up, and the muscles supplied by the cranial nerves seemed intact. The muscles were small, but there was no local atrophy, and the muscles gave

to the touch a feeling of peculiar softness. The skin of the lower extremities showed a degree of hard œdema comparable with that of myxœdema. The knee-jerks were always absent. The general health and the state of nourishment were good and there were no signs of rickets. The electrical reactions were not reported.

Case 19 (Lugenbühl [15]).—Female, aged 5 months. Maternal grandmother a tabetic, otherwise family history negative. Normal birth at full time. During pregnancy, quickening felt in usual way by mother. At birth it was noticed that limbs were motionless and flabby. Four weeks later, slight finger movements; thoracic muscles badly developed and functioning poorly; similarly with muscles of neck. Cutaneous and deep reflexes absent; normal sensation; no response to either faradic or galvanic stimulation. Facial musculature quite unaffected, and active to electrical currents. No affection of the thymus discoverable.

Four months of electrical and massage treatment have improved condition; child can now move toes, feet, hands, forearms.

Case 20 (Oppenheim [18]).—Child, aged 19 months, sex not stated. Natural birth. Family history negative. It was noticed not long after birth that the child could not move its limbs, though the trunk and face muscles appeared to function normally. The weakness was associated with extraordinary flabbiness of the muscles. Nine months passed before the child began to move its arms, and only in the last few weeks has it begun to move its legs, following on electrical treatment. It is well developed and nourished, with little if any reduction in the volume of the muscles, which felt doughy. Their tonus was markedly diminished; the tendon reflexes were all absent. The muscles did not react to mechanical stimuli nor to strong electrical stimuli, with the exception of feeble twitches which were obtained in the peroneus. No alteration in sensation; no impairment of sphincter control.

Case 21 (Rosenberg [21]).—Male, aged 2½. Family history negative. Mother stated that having experienced no quickening during the pregnancy she was afraid the child would be stillborn. The value of this statement is somewhat discounted by fact that the only other pregnancy ended in a three months abortion. Natural birth at full term. Bottle fed. Always able to suck and to swallow. Movements of head, eyes, face and arms always good; child learned to sit up at 7 months. The defect of leg movement escaped the notice of the parents till the child was 11 months, when they noticed knees and hips always gave way with the child's weight. Could neither stand nor walk. Well developed and nourished. No movement of thigh or leg, only of foot and toes. With painful stimuli, however, it was found that child could move legs at hip and knee, though feebly. Toe and foot movements fairly active. No atrophy of leg musculature; skin natural colour and temperature. Great hypotonia of leg muscles, but slight contracture of the hamstrings. Absence of knee- and Achillis-jerks. Proximal muscles of legs felt more doughy than the distal. Former did not react at all, either to mechanical or electrical stimuli, whereas with strong currents a slight response was obtained from the peronei. No

change in sensation. No sphincter trouble. Cutaneous reflexes not elicited. Deep reflexes present in the arms. Head and arm movements fair. No sign of rickets. Cranial nerves normal.

After thirty-one months treatment considerable improvement in movements at hip and knee.

Case 22 (Schüller [22]).—Male, aged 19 months. According to the mother's account, child was always weak, though never really ill. After learning to sit and to stand, during the last nine months it has gradually ceased to do either, and now it can no longer sit upright well. Very pronounced hypotonia of the leg muscles, without any wasting; absence of deep reflexes; great quantitative diminution in electrical excitability. Active movements of the legs limited; sensation normal; condition of bones and joints normal.

Case 23 (Spiller [25]).—Male, aged 22 months. Negative family history. Normal birth at full term. Breast fed until date of admission to hospital. When he was given cow's milk in an attempt to wean him he would always spit it out, and of late, since he had been taken from the breast, he had swallowed with some difficulty. He had never at any time been able to hold anything in his hand. He was well developed for a baby of his age. Muscles not wasted, flesh soft and flabby. Limbs were moved voluntarily at all joints, and there was merely weakness present. Deep reflexes in the legs not elicited. Sticking any of the limbs with a pin causes the irritated limb to be drawn away with considerable force. The hypotonicity of the limbs, especially the lower, was very great. Could sit alone only for a minute or two, and only when he is balanced, but his head fell slightly forward. Had never been able to stand; muscles of limbs react to faradic current. Atony of the abdominal walls.

When in hospital it could not be induced to take food, and was always fed nasally. It died not long afterwards, and the pathological findings are given above.

Case 24 (Tobler [26]).—Male, aged $1\frac{3}{4}$ when first seen, and observed for three subsequent years. Negative family history. Natural birth at full time. Breast fed for six months. From outset it was remarked that the child made little or no spontaneous movement. When first examined, plump and well nourished. No signs of rickets. Musculature well developed and symmetrical, but very weak and flabby. Kyphosis of the vertebral column; absolute tonelessness of limbs; great laxity of joint structures. No paralysis; on the contrary, there was movement both of arms and legs, of the former more particularly, but the movements were languid and weak. It was noted that they were better peripherally than proximally. Rose with great difficulty to a sitting position, but once sitting up could remain so. Tongue and eye movements normal; facial musculature rather inactive. Knee-jerks not obtained; electrical excitability to both forms of current either diminished or lost. Sensibility to pain and to electrical stimulation was not affected.

Two years later the child had grown mentally and physically; was well nourished, could feed itself, and seemed to try to make all the use it can of its limbs; still quite unable to stand. A few months later it died, apparently from diphtheria. No autopsy was obtained.

Case 25 (Variot and Devillers [27]).—Female, aged 6 months at its death. Mother remarked very little, and very feeble quickening during pregnancy. From the beginning the parents noticed the peculiar position of the child's arms, which were flexed at the elbow and adducted at the shoulders. Both arms and legs were immobile, and the whole of the musculature of the body was most abnormally flaccid. The head rolled about indifferently if it was not supported. When the arms or legs were lifted, they fell back as limply as the limbs in polio-myelitis. When the child was seated a marked spinal kyphosis was noticeable, which disappeared when the child was lying. The face was normal, and the child was able to suck quite well.

Under observation the movements of the patient continued excessively feeble, and the asthenia persisted. It was noted by the parents that the child was able to make movements of its limbs in the bath that were impossible out of the water.

It succumbed to broncho-pneumonia when six months old.

Clinical Abstract of Sorgente's Familial Cases, with a Clinical and Pathological Report of Another Case of the Same Group.

Case 26 (Beevor[1] [3]).—Male, aged 5 weeks. He was the youngest of eight children, of whom the first, second, fourth and eighth were similarly affected. The paralysis had become noticeable in these children at the following times after birth: in the first child at four weeks, in the second child at six months, in the fourth child at six weeks, and in the present patient it was obvious at birth. The other children of the family were aged respectively 14, 9, 8 and 1 year and 9 months; they were all healthy.

The mother had had good health during the pregnancy, but she had never felt any fœtal movements with this child. The child was born at full term and weighed 15 lb.; the birth was easy and natural. The infant was black from asphyxia when born and was at once noticed to be paralysed.

The child was well nourished and it was lively and contented. There was absolute flaccid palsy of all the voluntary muscles of the body with the exception of the muscles of the face and neck and the diaphragm; the intercostals were completely inactive. Very slight and feeble movements of the fingers of the left hand were possible. Faradic excitability in the affected muscles was completely lost, and to galvanism A.C.C. was greater than K.C.C. The special senses and cranial nerves were normal and no bulbar symptoms were present, the child being able to suck powerfully. There was complete loss of sensibility to all forms of stimulation over the whole of the body and limbs, reaching as high as the upper limit of the fourth cervical segment; above this limit sensi-

[1] This case was published by Dr. Beevor in *Brain*, 1902.

bility appeared to be normal. Reflex action of the bladder was performed normally and the anus was not patulous.

The knee-jerks and the other deep reflexes were absent, but the superficial reflexes were present, the plantars showing a slight extensor response. Under observation the muscles wasted rapidly, the respiration became increasingly embarrassed, and the child died of respiratory failure at the age of eight weeks.

The pathological examination was conducted by Dr. F. E. Batten. The external appearance of the nervous organs was normal. The tissues were examined by the Marchi, Weigert-Pal, van Gieson and the Stroebe methods. The brain, cerebellum, brain-stem and the cranial nerve nuclei were normal. There was intense atrophy of the anterior horn cells throughout the spinal cord less marked in the fourth cervical segment. There was intense recent degeneration of the fibres of the posterior columns throughout their extent, but the posterior roots were not degenerated. There was great atrophy of the fibres of all the affected muscles.

Case 27 (Sorgente [24]).—Male, aged 27 days. Natural birth at full term. No quickening during pregnancy. Breast fed. From the day of its birth unable to move arms or legs. Well nourished and developed; plump legs, with complete flaccidity of the muscles. Little voluntary movement of head; respiration entirely abdominal, with indrawing of lower thoracic margin during inspiration. No alteration in sensation. No voluntary movement of limbs in response to painful stimuli. Absence of cutaneous and deep reflexes; no reaction in muscles of legs to either faradic or galvanic current; minimal reaction in arms. During ten days treatment in hospital, signs of movement in arms, and breathing became more of costo-abdominal type. Death three days later from bronchitis. No autopsy obtained. Five hours before death, general convulsions, with rotation of the eyes, shaking of head, and tonico-clonic movements of all the limbs.

Case 28 (Sorgente [24]).—Sixteen months later 5-day-old female child of same parents was brought to hospital. Mother ill and weak during pregnancy, and had not observed quickening. Child well developed; flaccid paralysis of legs, flaccidity of arms, but some slight movements in them. Otherwise, clinical picture as with previous child. Death after 15 days, preceded during twenty-four hours by general convulsions.

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THE STRUCTURE AND FUNCTIONS OF THE CEREBELLUM EXAMINED BY A NEW METHOD.

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PART I.—METHODS.

I.—INTRODUCTION.

THE methods and experiments described in the following pages are the direct outcome of an investigation into the anatomical relations of the cortex of the cerebellum to its nuclei and peduncles, and to the rest of the brain and spinal cord. An account of that research was published in *Brain* in the spring of 1905.

When we began that work (1903) the view had been gaining ground that there was no direct path from the cortex of the cerebellum to the peduncles or to the spinal cord, and had been advanced by distinguished observers, especially Ferrier and Turner, Risien Russell and Thomas, who expressed themselves more or less definitely in favour of this opinion, and supported it with observations furnished by their own experiments. But although the evidence adduced established a strong probability we did not consider that it amounted to proof, as the conclusions were founded on lesions involving both cortex and nuclei, or complicated with injuries to other parts. Nor were all the conclusions of the authors absolutely definite. Marchi originally described a direct descending path in the spinal cord derived from the cerebellum. Ramon y Cajal spoke of this tract in a rather ambiguous way, leaving the reader in some doubt whether he recognized the tract himself or was merely quoting Marchi by calling it the *via descendente*. Ramon y Cajal also described some fibres passing from the cerebellar cortex to the superior peduncle.

Thomas in his classical work ("Le Cervelet"), though generally supporting the view that no direct cerebello-spinal path existed, yet gave illustrations of a case of cerebellar lesion exhibiting degenerated (tecto-spinal) fibres in the spinal cord; and though he stated that there was an accidental lesion of the posterior colliculus which might have produced degeneration of such a spinal tract, Thomas was of opinion that these fibres were derived from the cerebellum.

The later illustrations of Probst all showed more or less injury to the nuclei, and though he made the deduction that the amount of degeneration seen in the peduncles or beyond them was proportional to the amount of injury to the nuclei, and was therefore derived entirely from them, the lesions were not sufficiently defined to justify these conclusions.

Considering this position of the subject was unsatisfactory, and that besides the anatomical question the much broader one of the respective functions of the cerebellar cortex and nuclei was as yet wholly undetermined, we resolved to try and find some more conclusive evidence by which to decide these points. The failure of previous experiments to afford absolute proof appeared to be due in all cases to the fact that the lesions had not been sufficiently limited, and it seemed most probable that if special precautions were observed to avoid this defect in a series of cortical lesions, following the resulting degenerations by Marchi's method, definite information regarding the course and destination of the cortical fibres would be afforded.

The results justified these anticipations. Small lesions of the cortex were made by one of us (V. H.) in anæsthetized animals—monkeys, dogs and cats. In thirteen cases the cerebellar nuclei were absolutely untouched, the lesions being strictly confined to the cortex; and of these cases, though there were abundant well-stained fine fibres passing to the adjacent folia (arcuates) and to the intrinsic nuclei, none showed degenerated fibres in any of the peduncles or in the spinal cord; this evidence appeared to us conclusive.

We did not think it necessary to perform any more experiments for the purpose of accumulating evidence on this question, but accepting the data as correct have endeavoured to follow up the indications they afforded. This view was corroborated by the appearance (after the publication of our paper) of an important research by van Gehuchten, who quite independently came to the same conclusion from experiments on another species of animal, viz., the rabbit.

As a result of these experiments we were led to the conclusion that the cerebellar cortex is essentially a recipient organ (Edinger); its efferent

fibres passing to neighbouring folia and to the cerebellar nuclei, the latter being regarded as stations interposed between the efferent cortical fibres and the rest of the nervous system. Collectively, therefore, these nuclei might be considered the focus of cerebellar activity, and regarding this as the standpoint from which further investigations of their structure and function must proceed, we resolved upon a systematic inquiry into the function of the cerebellar cortex and nuclei respectively.

On making a general survey of the subject before us, and considering the most promising methods of research, we were confronted with the following preliminary difficulty: The nuclei of the cerebellum in monkeys, dogs, and cats are small, deeply situated, and not very accessible for excitation experiments, while it is evident that to get results of any value by Marchi's degeneration method, lesions must be precisely limited to the nuclei, or, if possible, to parts of them, and that such lesions must not only be accurately localized but also produced without noteworthy injury to other structures, for we had already observed the difficulties and confusion which such complications have introduced into the discussion of the subject. An essential preliminary, therefore, to further progress was to find some method which would satisfy these conditions, viz., a means of producing lesions of the cerebellar nuclei which should be accurate in position, limited to any desired degree in extent, and involving as little injury as possible to other structures (*see* fig. 20A, p. 98). Neither puncture with a small knife, nor galvano-cautery, nor the injection of acids or other fluids appeared to us to fulfil these conditions adequately, and we therefore discarded them. At this time (1904) we were unaware of the experiments of Sellier and Verger (see p. 86), in which insulated needles were used for the production of electrolytic lesions in the brain, and we arrived independently at the same point after a number of preliminary experiments which will be referred to presently. At first, although the application of an electrical current to the nuclei by means of needles insulated to within a short distance of their points appeared most likely to serve our purpose, we were doubtful whether it would be better to employ two insulated needles and a current of high tension, thus obtaining destruction by sparks, or to use a single needle and a surface electrode with faradism or electrolysis; it is sufficient to say here we soon abandoned both the spark and faradism. The former was too violent and difficult to regulate, and the latter set up vigorous convulsive movements which are too severe to allow of the application being maintained long enough to produce an

effective lesion; but the electrolytic method appeared promising from the first, and after several years experience we regard it as satisfactory. The conditions under which a lesion should be made, and which we have enumerated already, are not very exacting, but, such as they are, electrolysis fulfils them in a way which leaves little to be desired. As we shall explain more fully later, electrolytic lesions of the brain, especially anodal ones, are quickly and easily produced with very slight injury to any other parts; their size can be accurately regulated, their form depends on the nature of the electrode, they are precisely defined, and the necrosed tissue passes in all directions almost abruptly into the uninjured tissues, which do not appear to be even temporarily affected by the lesion; while, finally, with the stereotaxic instrument we are going to describe, we are able to direct a protected stimulating and electrolytic needle to any desired part of the brain with very fair accuracy. All these particulars are included in the method which in this paper we propose to explain fully before giving in a separate communication the results we have obtained with it on the cerebellum. We shall begin with an account of our method of cranio-encephalic topography and measurement, followed by a brief discussion of the subject of electrolysis of central nerve tissue, including the physical and chemical characters and microscopical structure of the lesions, the different effects of anode and cathode, concluding with a discussion of the methods of electrical stimulation we have employed on the cerebellum. In a second communication we shall describe the results obtained by these methods on the structure and functions of the various parts of the cerebellum and cognate centres; this will include an account of the anatomical position of a great number of lesions, the course of the degenerated fibres and tracts they have produced, and an analysis of the functional changes and clinical symptoms which have been associated with them.

A preliminary account of our methods and of the stereotaxic instrument was published by one of us (V. H.) at the meeting of the British Medical Association at Toronto, August, 1906.

II.—Rectilinear Cranio-Encephalic Topography.

The first requirement in a research of this kind is the establishment of the relations existing between the exterior of the head in animals and its encephalic contents, especially in the monkey, but also in orders as far apart as the carnivora, insectivora, and birds.

As yet relatively little information exists on this question, although it is of fundamental importance in anatomy.

For the higher vertebrates the valuable drawings (especially fig. 9, p. 69) in the text-book by Flatau and Jacobson [3] are useful indications, but for our purpose it was necessary to have not only a precise knowledge of the proportionate relations, but a means of reaching any definite spot in the encephalon, and we were therefore compelled to begin *de novo*, and, as will be seen directly, have adopted a method in which the objective is determined by measurement from a zero inside the encephalon, and not by the usual projection on the exterior and measurement from it.

On the question of correct technique in making cutting lesions in the central nervous system, the most important communication that has recently appeared is that by Wilhelm Trendelenburg [24]. After quoting the well-known methods of Longet, Nawrocki, Dittmer, Cyon, Woroschiloff, Probst, and Corona he points out that it is possible to devise an apparatus which consists of two parts: first, a model in brass foil of a sagittal section of that portion of the nervous system in which it is desired to make a lesion; and, second, a knife ingeniously devised of stout steel wire, so that it is possible to guide its one extremity by a hole in the brass plate (such hole representing the desired lesion), while the other extremity enters the brain. It will be understood that the model is fixed above the brain in which the lesion is to be made, that the knife is made to follow the outline in the model, and that its parallel movements and adjustment are cleverly obtained by a lazy-tongs arrangement, for movements in two planes, frontal and horizontal, that in the vertical plane being provided by sliding up and down an upright. It will be seen, of course, that this *myelotom*, as Trendelenburg names it, does not fulfil the conditions we feel must be satisfied. It is, however, a great advance on the cannulæ and hook-like stilettes, devised by Veyssière and subsequently employed by Bechterew, Probst, and other workers, since it includes an accurate control of the cutting point during the whole operation.

To meet our immediate necessities, and at the same time to provide a plan of general application to the whole encephalon, a method of rectilinear topography and a stereotaxic instrument for applying it to direct an insulated needle to any desired point in the brain for excitation or electrolysis were devised by one of us (R. H. C.), and we have employed them for the last three years for the study of the structure and functions of the cerebrum and cerebellum in various animals.

Topographical Data and Measurements.

The difficulty of arriving at the precise localization of a point in the deep structures of the brain is due to several causes which have been generally recognized but not hitherto satisfactorily met. The first and most obvious one is that of making accurate measurements of the curved surface of an irregular sphere, like the head, especially when there are few constant and trustworthy features to serve as fixed points, while of these the precise definition is obscured, and their value more or less impaired by the mobile integument and muscles which cover the cranium. The initial difficulties are much enhanced when the ultimate objective to be localized is not on the surface, but deeply situated and probably at an uncertain distance within the cavity of the skull, and when allowance must be made for variations of thickness of the bones and their coverings, and of the size, shape, and symmetry of the structures concerned. We find, however, that a practicable and, on the whole, satisfactory solution of this problem may be attained by dividing the cranium into eight segments, by three section planes at right angles to each other, *e.g.*, sagittal, horizontal, and frontal. As a result of these sections, each segment presents the three internal surfaces of a cube, and every point in it can be identified by rectilinear measurements from those surfaces or section planes, *i.e.*, from their *internal* boundaries. By this means the irregular curved surface, which corresponds to the three outer sides of the cube, is not involved in any way and needs no further consideration.

In short, instead of employing the usual method of endeavouring to project the detailed structure of the interior of the encephalon on to the surface of the head, we measure the position of the deep parts of the brain by their relation to three section planes.

The advantage of applying this principle, which, so far as we know, is new in the topography of the brain, to the localization of structural detail for the identification and record of lesions, and for the mechanical direction of an insulated needle for excitation or electrolysis, is obvious, and its utility will become more evident as we proceed to consider the details of its practical application.

The essential points of this principle may be briefly summarized as follow:—

(1) Any irregular solid may be divided by three section planes in three dimensions into eight segments, in each of which the three internal surfaces are those of a cube.

(2) In any solid body a constant point which can be measured from plane surfaces, representing the three dimensions of a cube, can be identified by three perpendiculars of correct length dependent from those surfaces, and it is the only point where those perpendiculars can meet.

(3) A needle may be substituted for any of these perpendiculars, and in order that it may be directed mechanically to any required point in any of these rectilinear segments, an instrument is necessary which will introduce it in a direction perpendicular to one surface, and therefore parallel to the other two, to any required distance from the first surface, any required distance from the others, *i.e.*, the needle must have a regulated movement in three dimensions.

The Determination of the Three Section Planes of the Head.

These principles are applicable to the identification of any point within the brain of a living animal and to the direction of a needle to it, provided that the conditions as defined are fulfilled. Now it is obviously practicable to divide the cranium by three section planes, which in the living animal are imaginary (definition 1). We can construct an instrument which meets the requirements of definition 3. The only difficulty lies in the determination of "constant points which can be measured from plane surfaces representing the three dimensions of a cube" (definition 2). This measurement cannot be effected in the living animal; the distance of a selected point must therefore be known from the measurement of other heads, and can be trusted only so far as these data are constant. Hence it is essential to find a method of determining section planes, which are themselves constant and can be proved by experiment to have a constant relation to any selected point within the brain.

The simplest method of selecting section planes of the cranium would be to bisect its longest diameters in three dimensions by planes perpendicular to them. This is not practicable in the case of the vertical diameter because of the structures of the neck, and in order to determine the frontal and median sagittal planes, by bisecting the longitudinal and transverse diameters of the cranium, we must first define those diameters. But there are no landmarks on the surface of the skull beneath the integuments which are sufficiently clear and precise to determine an accurate longitudinal diameter, though for transverse diameters we can utilise such prominent features as the eye and ear. The simplest method, therefore, is to begin with these structures and adopt the centre of the

external auditory meatus and the centre of the lower margin of the orbit on both sides for the definition of the horizontal plane, or a basal plane to which the horizontal section plane is parallel but about 10 mm. nearer the vertex.

Beginning with this basal plane we can define the frontal section plane as perpendicular to the horizontal and passing through the centres of both meatus, and the sagittal section plane as bisecting the cranium perpendicular to the other two (section planes).

It will be seen (p. 63) that this order will be followed in the application of Clarke's stereotaxic instrument. The horizontal frame is adjusted and fixed to the four points (eyes and ears) of the basal plane. By the same process the frontal zero plane is brought into place perpendicular to the horizontal plane and cutting the centres of both meatus, and the sagittal zero plane, perpendicular to the other two, is made to correspond with the median sagittal plane of the cranium by four graduated lateral clamps.

We consider the above are the most satisfactory section planes; we have verified them by the methods of drilling and passing ivory needles and making frozen sections as described elsewhere (p. 59), and, as far as our experience goes, their relations to the most important structures of the brain are constant, with such corrections for size and symmetry as are necessary, and also quite practicable (*vide* p. 82).

Various anatomical features, such as sutures of the cranial and facial bones and surface markings of the brain, will be found useful for verification of the accuracy of adjustment of the instrument.

It will be noticed that the centre of the external auditory meatus corresponds to the auricular point of anatomists, and the basal plane differs very slightly from the Frankfort-Munich plane, the latter being determined by the upper margins instead of the centres of the external auditory meatus.

Reference has been made to the situation of the zero horizontal section plane being about 10 mm. above the basal plane; the object of this is to make it more central. The advantage of making the section planes as central as possible is not only that it brings them into closer relation with the most important structures of the brain, but as all measurements are made in both directions from each of the three section planes which count as zero, the margin of error in measurement is reduced.

The precise position of the zero horizontal section plane is therefore a level determined by what has been found convenient in practice in the animals we have used. Thus in the average *Macacus rhesus* the

distance from the centre of the auditory meatus to the vertex, perpendicular to the base line, is 40 mm.; in the cat it is about 30 mm.; in the hedgehog about 20 mm. But whilst in the *Macacus rhesus* the inter-aural line (that is a line passing from the centre of one meatus to the other) passes through the pons, in the cat it touches the inferior surface of the pons, while in the hedgehog it is still further ventral and lies in the basi-occipital bone. This has suggested to us that the zero-horizontal section plane in the *Rhesus* should be placed at one-fourth of the distance from the meatus to the vertex, that is 10 mm. on the average above the basal plane (passing through the auricular point in the meatus and the orbital border). In the cat one-third of the distance from the meatus to the vertex, and in the hedgehog one-half the distance, places the zero horizontal plane at proportionately the same region of the encephalon. In all these animals the horizontal section plane will then be about 10 mm. above the base line and convenient for measurements above and below it. For these animals, therefore, we have adopted this arrangement, but possibly future investigators employing different animals may find other proportions more convenient.

The Subdivision of the Encephalic Segments into Lamellæ and Cubic Millimetres.

As already described, the whole encephalon is divided by the three zero section planes into eight segments, which are, we designate, right and left frontal, occipital, temporal and cerebellar, and each segment of the encephalon presents on its inner aspect three rectilinear surfaces corresponding to the three section planes—sagittal, frontal, and horizontal. On frozen sections of an animal's head, the preparation of which will be presently described, the distance from any point of these three surfaces of any segment can be measured and then, for an actual experiment, by means of the stereotaxic instrument, which is adjusted by these indications and carries an excitation and electrolyzing needle travelling on graduated guides in each of the three planes, it is easy to direct the latter to a similar point in an intact head. The identification of the desired point and the direction of the needle are made practicable by finally subdividing the segments into cubic millimetres as follows: Each segment is theoretically subdivided into slices or lamellæ 1 mm. thick in each plane, and each lamella is divided by lines parallel to the other two planes into millimetres. For the study of the topographical detail and structure of each lamella working "charts" are made by

cutting frozen heads in a special instrument into lamellæ in all three planes. To secure the identification of the section planes perpendicular to the lamellæ thus prepared fine ivory knitting needles are previously introduced by a drill. For instance, for lamellæ in sagittal sections, two fine ivory rods are passed transversely from the auditory meatus and orbital margin of one side to the corresponding points on the other; each sagittal lamella therefore shows a section of the two ivory needles, a line joining which is our base line. A glass plate (fig. 1), divided by ruled

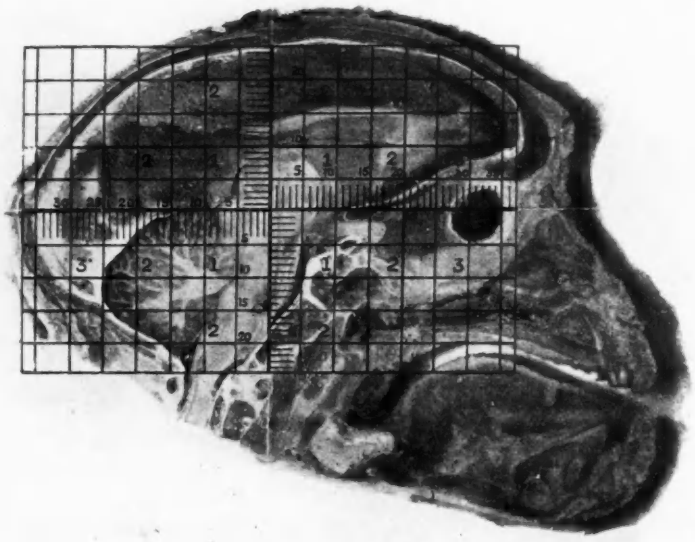

FIG. 1.

Sagittal section of frozen head of Rhesus, and millimetre glass plate.

lines into square millimetres and by two bold lines crossing in the middle into four parts, is then placed on the surface of the lamella, and with the aid of the centres of the ivory points the glass plate is adjusted so that the two bold lines coincide with the frontal and horizontal lines or section planes. The distance of any point in the lamella from these lines can then be directly read off, and as the number of the lamella indicates the number of millimetres from the median

section plane, the exact[1] distance of the selected point from the three inner surfaces of the segment in which it lies is known. Though it is useful to have several series of lamellar sections cut in all three planes, it is best to make records and references as far as possible to one plane only, and the sagittal plane is the most convenient for this purpose.[2] Further advantages of such limitation are: much less confusion and greater brevity of reference. If it is understood that all lamellæ not otherwise specified are situated in the sagittal plane, the word sagittal is superfluous. Lamella vi. then signifies a lamella in the sagittal plane 6 mm. from the median sagittal plane. It is also convenient to indicate the ordinates, *i.e.*, distances above or below the zero horizontal plane in the ruled plate, and so in the lamellæ by letters of the alphabet, while the abscissæ or distances in front or behind the zero frontal (inter-aural) plane are denoted by numerals. If the sagittal plane is adhered to, one soon learns that letters refer to millimetres above and below the horizontal line and numerals to millimetres before and behind the frontal line. At first the use of letters to indicate numbers is rather confusing, but after a little practice one remembers the numbers the letters correspond to without much difficulty. The advantage of having a short and easily recognized reference to any cubic millimetre will be appreciated in practice. Thus a rhesus' brain contains about 200,000 c.mm., and yet by the method described any given cubic millimetre can be identified by a reference as short as the following: *Left frontal segment, lamella* v. *J.* 6. Such a statement refers to a cubic millimetre in the left frontal segment 5 mm. to the left of the median sagittal plane, 10 mm. above the zero horizontal plane, and 6 mm. in advance of the inter-aural or zero frontal plane. With that reference it is easy to select from the frozen sagittal sections lamella v., and by applying the ruled glass plate with the help of the points marked by the ivory, so that the cross coincides with the frontal and horizontal lines, to identify the deep structures which correspond to J. 6.

This sketch of the principles of what may be called rectilinear topography may serve to explain the measures required for its application, which must now be rather more fully described.

Working "charts."—These consist of a series of sections of the

[1] For corrections due to size, &c., see p. 82.

[2] Probably, too, most investigators visualize the encephalon sagittally, *i.e.*, as a lateral view, the head being in the anatomical position with the visual axes horizontal, although it has unfortunately been the stereotyped custom to make the large majority of anatomical researches by sections in the frontal plane only.

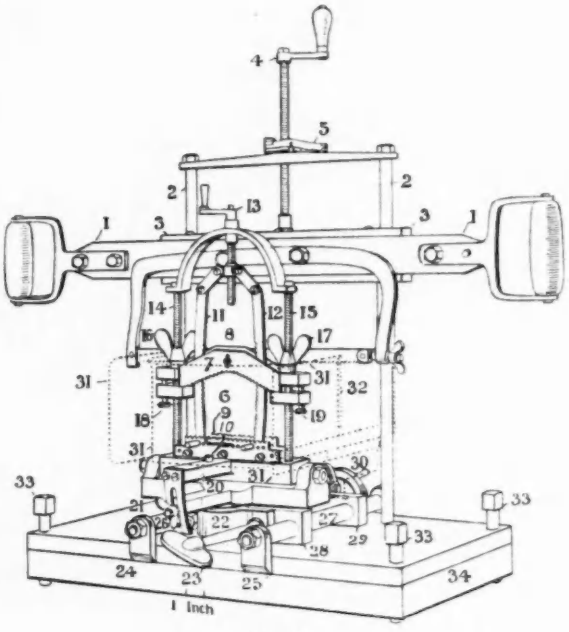

FIG. 2.

Clarke's Saw for cutting sections of frozen heads 1 mm. or 2 mm. thick.

1 Hack saw working on horizontal and vertical guides.
2 Vertical guides for saw.
3 Horizontal guide for saw.
4 Screw for raising and lowering saw.
5 Grip with spring catch, in which screw 4 works.
6 Placed in centre of head vice.
7 Posterior blade of upper jaws of head vice.
8 Anterior blade of upper jaws of head vice.
9 10 Anterior and posterior lower jaws of head vice.
11 12 Vertical jaws of head vice.
13 Screw for approximating vertical jaws of head vice.
14 15 Screw guides for upper jaws of head vice.
16 17 Fly nuts for depressing upper jaws of head vice on screw guides (14, 15).
18 19 Screw for adjusting upper jaws of head vice.
20 Rocking adjustment of head vice.
21 Fly nut for clamping rocking adjustment (20).
22 Rotatory adjustment of head vice.
23 Screw for clamping rotatory adjustment (22).
24 25 Fixed brackets supporting guides of travelling stage of vice.
27 Right guide of travelling stage of vice.
28 29 Travelling stage of head vice.
30 Graduated wheel for moving travelling stage of vice on guides—One complete turn = 2 mm. movement of stage.
31 Zinc tray (shown by dotted lines) to confine CO^2 snow.
32 Dotted lines show gap in sliding side of tray for saw.
33 Levelling screws of foot-plate.
34 Foot-plate.

frozen head of an animal of the same species, and as nearly as possible of the same size as that which is to be used for the experiment. These sections are cut with a saw in a special instrument (Clarke) (*see* fig. 2) 2 mm. thick, parallel to one of the section planes, and mounted in glycerine jelly between glass plates. Each section shows two lamellæ, one surface of each lamella being visible under the glass plate which covers it. The lamellæ are measured and numbered from the section plane to which they are parallel. Thus they will be right and left sagittal, superior and inferior horizontal, anterior and posterior frontal lamellæ in their respective planes, and the number of any lamella indicates the number of millimetres from the zero section plane to its distal surface, *i.e.*, lamella i. lies between the section plane and a section 1 mm. from it. It is convenient to have a series of lamellæ in each plane, but the sagittal is most important, since we make, as already stated, all records and references in it unless otherwise indicated.

Preparation of the head.—Heads of different sizes are injected with warm 10 per cent. formalin, or equal parts of this and Müller's fluid. If not injected before the vessels have time to contract, the injection should be put off for several hours till the contraction of the vessels has begun to pass off; only moderate pressure should be employed, 0·5 to 1 metre of water is sufficient. After the injection is completed two or three holes are trephined in the skull, and the head is suspended in equal parts of 10 per cent. formalin solution and Müller's fluid of double strength; it is ready to cut in a few days.

Drilling.—It has been explained already that the directions of the section planes are identified by passing two ivory knitting needles (size No. 13 or 14) in one of the section planes perpendicular to that in which the sections are made. For this purpose, and for the attachment of the stereotaxic apparatus later, it is necessary to obtain an accurate centreing of the external auditory meatus, which is accomplished as follows. Fig. 3 represents the drill, which is passed through the auditory meatus in the following manner: The same ear plugs which are used for subsequently adjusting the head in the stereotaxic instrument are employed for the drilling, being bored for this purpose. These ear plugs are made by modelling from casts of the external auditory meatus, conical plugs of different sizes so as to fit different meatus, and bent 3 mm. or 4 mm. from the base at an angle of about 20°. The floor of the meatus in the rhesus and in most animals forms a slight elevation a little internal to the external orifice and, in the rhesus, is then directed downwards and forwards. The bend in the conical plug divides it into two

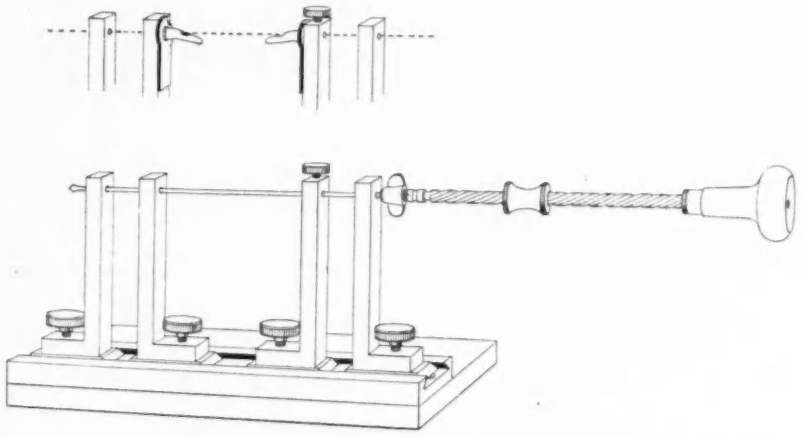

FIG. 3.

Clarke's drilling instrument.—For defining the relation of external to internal structures and determining section planes by means of ivory needles passed through corresponding points on opposite sides of the cranium and cut in frozen sections.

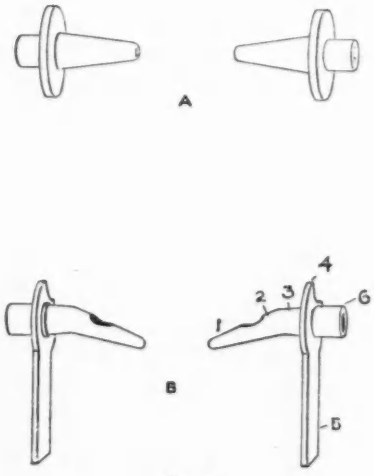

FIG. 4.

Ear Plugs.

1, cone; 2, angle; 3, barrel; 4, disk; 5, flange; 6, funnel.

parts, an inner conical part (the cone) and a short outer cylinder, the barrel (fig. 4). A disc and flange are attached 3 mm. or 4 mm. from the bend, and the barrel is continued and expands slightly to a few millimetres beyond the external surface of the disk to form the funnel (fig. 4), which admits the cylindrical end of the aural pivots in the stereotaxic instrument or the nipples of the drilling apparatus. For passing the ivory needle and marking the inter-aural line, the ear plugs are introduced into the meatus and the two inner uprights of the drilling apparatus (*see* fig. 3) are brought together in the slide till the nipples enter the funnels of the ear plugs; they are then pushed home and clamped, the head being supported by the ear plugs and nipples on the two inner uprights. The drill is passed first on one side and then on the other through the perforation in the two uprights, by which accuracy of direction is secured, the petrous bone being drilled through on each side to the middle line; then a steel needle is passed the whole distance from one outside upright to the other (fig. 3), and finally the ivory needle. For drilling between the malar margins of the orbit the points are marked on each side, then the head is fixed in a clamp between the two uprights and drilled from each side as before, and the ivory needle can then be passed in the place of the drill. The points at which the drills are entered for different section planes should be marked by putting the head in the stereotaxic instrument, and it is desirable to do this and to drill when the head has been but recently fixed (*i.e.*, before it has been rigidly hardened), so that the soft parts of the auditory meatus are practically in a natural condition.

Cutting.—The instrument for cutting frozen sections has been altered from time to time, but its general construction can be seen in the illustration (fig. 2). It consists of a hack-saw working in vertical (2) and horizontal guides (3), the saw being raised or lowered by a screw which can be released by a catch (4). The head is carried on a travelling stage which is moved in guides at right angles to the saw by a graduated wheel (30), one complete turn of which moves the block 2 mm. The stage (28) carries a head vice (6) on a plate with rotating and rocking adjustments (20-22) by which the head can be adjusted in two dimensions after it is fixed in the clamp. Two zinc plates (31) are fixed to the front and back of the travelling stage (28), and two lateral ones, attached by a sliding movement to its sides (32), confine the frozen CO_2 which is used to freeze the head, and the lateral plates have a gap (32) directly beneath the saw in which it descends. Some of the frozen snow escapes through these gaps, but not much. The head can be gripped in the clamp by one

side, by the face, or by the base for sections in the sagittal, frontal, or horizontal planes. Having been secured it is next aligned by the adjustable plate guided by plummets suspended from the ends of the saw and by the surface markings on the head. A superficial saw cut is made to begin with in the median section plane, *i.e.*, for sagittal sections in the median sagittal line, and the distance from this line to the limit of the furthest sections to be cut is measured and marked. The head is then packed with frozen CO_2 moistened with ether. Freezing usually takes about half an hour. If frozen too hard the sections are too brittle and apt to break. If too soft they are apt to bruise and tear, but the right degree is soon learned with a little practice. When freezing is apparently complete the screw is worked till the position chosen for the first saw cut is brought directly under the saw and the first slice removed. If the surface, which can now be seen, is properly frozen its distance from the median section plane is measured with a depth gauge, the plate of which is applied to the cut surface, while the sliding bar of the gauge terminates in a knife edge which fits into the superficial saw cut previously mentioned, and gives the distance in millimetres of the cut surface from the section plane, that is to say, the number of the lamella which that surface represents. A glass plate is then smeared with gum and applied to the cut surface, to which it immediately freezes and protects the next section while it is being cut. The block is now moved forwards 3 mm. by the screws, so that the saw cut and *débris* being equivalent to 1 mm., the section will be 2 mm. thick. As soon as it is sawn through it is placed in a dish of water, the number of the section and the distance of its surface being written on the glass plate. The same operation is repeated till all the sections are cut. They must then be carefully cleaned from the saw dust and *débris* in water, and left for a couple of days in equal parts of glycerine and water to dissolve out some of the formalin and chromates, as these have a tanning effect on the gelatine of the glycerine jelly which is apt to be troublesome. The sections are permanently mounted in glycerine jelly.

It is right to mention that there is a difficulty in mounting in glycerine jelly owing to the shrinking of gelatine produced by formalin and chromates, even after soaking the sections in glycerine and water. The most convenient way of mounting them is to make cells with glass plates large enough to include the section, and walls of square glass rods 3 mm. or 4 mm. diameter. When dry the cell is filled with warm glycerine jelly, and the section introduced with care to avoid bubbles. After a time the gelatine shrinks, air may find its way in, and occasionally the shrinkage

breaks the glass plates and the sections have to be remounted. The number of the lamella should always be immediately written on the glass covering the section with enamel paint.

General Conclusions on the Topographical Relations of the Encephalon in the Macacus rhesus.

From a large series of measurements of heads of *Macacus rhesus* and in a few cases of *Macacus cynomologus* we have been able to construct a

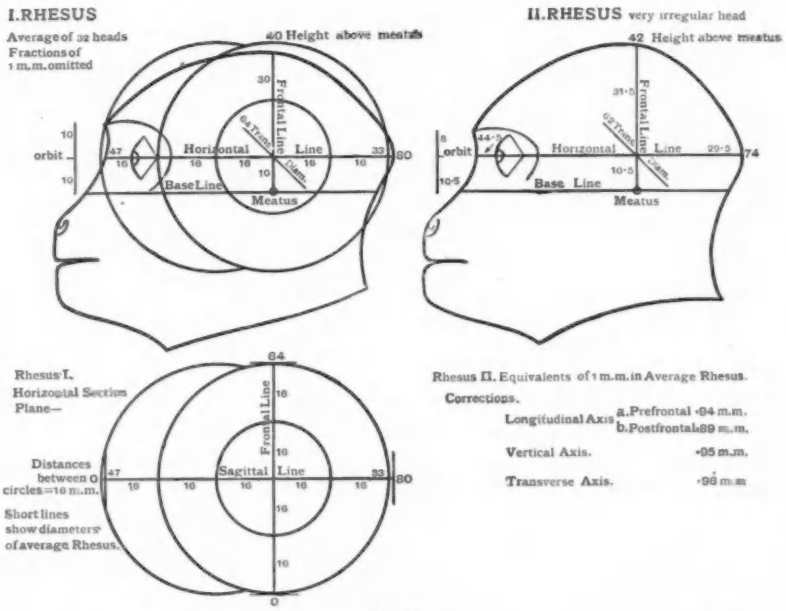

FIG. 5

Drawing of sagittal sections of heads of two Rhesus. I. Average size, and II. an irregular head. To illustrate measurements.

scale of averages for the former animal, and before describing the stereotaxic instrument we use for excitation and electrolysis we may perhaps with advantage first recount the general dimensions of the head in a *Macacus rhesus*, whose total body (head and trunk) length is about 320 mm. This being the commonest and most convenient size, we have as far as possible employed it only.

In fig. 5 is a reduced outline from a drawing on millimetre ruled paper showing the dimensions of a rhesus' head taken from an average of between thirty and forty specimens (avoiding fractions of 1 mm.). The base line passes through the centre of the lower margin of the orbit and the centre of the auditory meatus. Its length longitudinally is not used for calculation. Perpendicular to the base line is the frontal line, representing the (inter-aural) frontal section plane and erected from the centre of the meatus to the vertex; in the average rhesus it is 40 mm. in length. The greatest vertical diameter of the orbit is next taken and found to be 20 mm. on the average, or exactly half the height of the frontal line. On this point the constancy of the dimensions of the orbit in *Macacus rhesus* deserves some attention in view of opinions prevailing among craniologists on the value of orbital measurements. It is not a little remarkable that in examples of this species of monkey about 320 mm. long, the greatest vertical height of the orbit should rarely vary more than 0·5 mm., or at the outside 1 mm. from a total (greatest depth) of 20 mm., and in the large majority of cases not at all.

Further as regards symmetry any difference between the two orbits when present (and this is extremely rare) never exceeds 0·5 mm. It follows, therefore, that the determination of the lowest point in the lower margin of the orbit gives very satisfactorily the anterior point for the construction of the base line. To obtain the next convenient dimension, namely, the horizontal zero section plane, it will be seen that half the orbital height and one-fourth of the average frontal line are in both cases 10 mm. on the average. At this level, therefore, viz., one-fourth of the frontal line, we draw parallel to the base line the horizontal line representing the zero horizontal section plane, which extends from about the nasion to the occiput. Level in front with a line joining the two inner canthi, from nose to inter-aural plane it measures 47 mm. on an average, and from this plane to occiput 33 mm., making an average total length of 80 mm. Finally the greatest transverse diameter of the frontal plane is taken with callipers and found to be maximal at about the level of the horizontal plane and 64 mm. on the average. The point where these section planes meet in the median plane is zero, and all measurements are reckoned from it, as we have already indicated on p. 50. Two interesting points may be noticed in the above measurements: one is that the frontal line (the median section of the inter-aural plane) is exactly double the vertical diameter of the orbit, the other is the relation of the number 16 to several of the average measurements; thus it is

one-fifth of the longitudinal and one-fourth of the transverse diameter in the horizontal plane. In some animals with the same total longitudinal measurements the frontal line is 1 mm. further back, making the division of the longitudinal diameter 48 and 32 instead of 47 and 33 mm., these being also multiples of 16 in the proportion of 3 : 2, and in the horizontal section plane itself the relations of this number are still more striking, for the section of the skull at this level is almost exactly represented by one circle with a radius of 32 mm. and its centre at zero and half a circle with the same radius at a point 16 mm. further forward on the median sagittal line. Probably the average of a still larger number of (320 mm.) rhesus monkeys will differ a little from this, but the relative proportions are not likely to alter much, and accumulated experience proves that the above-stated figures will continue to be accurate guides.

III.—Description of Clarke's Stereoscopic Instrument Employed for Excitation and Electrolysis.

The application of the foregoing facts to our experimental investigations has been effected by an instrument, the general plan of which will be most easily obtained by an examination of the illustrations. It would be very tedious to follow a minute description of every screw and detail, and the purport of any of these can be ascertained by referring to the figures and letterpress, consequently no more will be attempted in the text than a short explanation of the essential features and their direct application to the animal's head.

The foundation of the stereotaxic instrument is a rigid quadrilateral rectangular frame (the "horizontal frame") the ends of which (the "nasal" and "occipital" bars) can be approximated by joints which slide on the lateral bars. The lower border of this frame, which is in the same plane on all four sides, is adjusted so as to correspond accurately with the zero horizontal section plane of the head and is fixed in this position on the skull by four lateral screw points all furnished with millimetre scales, so that in addition to fixing the frame they make the median sagittal line of the frame coincide with the sagittal section plane of the head. It will be seen directly that the horizontal pivot bars articulating with the ear plugs in the auditory meatus, on which the topographical adjustment of the horizontal frame primarily depends, also indicate the points of incidence of the perpendiculars to the horizontal

[1] The instruments were made by Messrs. Swift and Son, Tottenham Court Road.

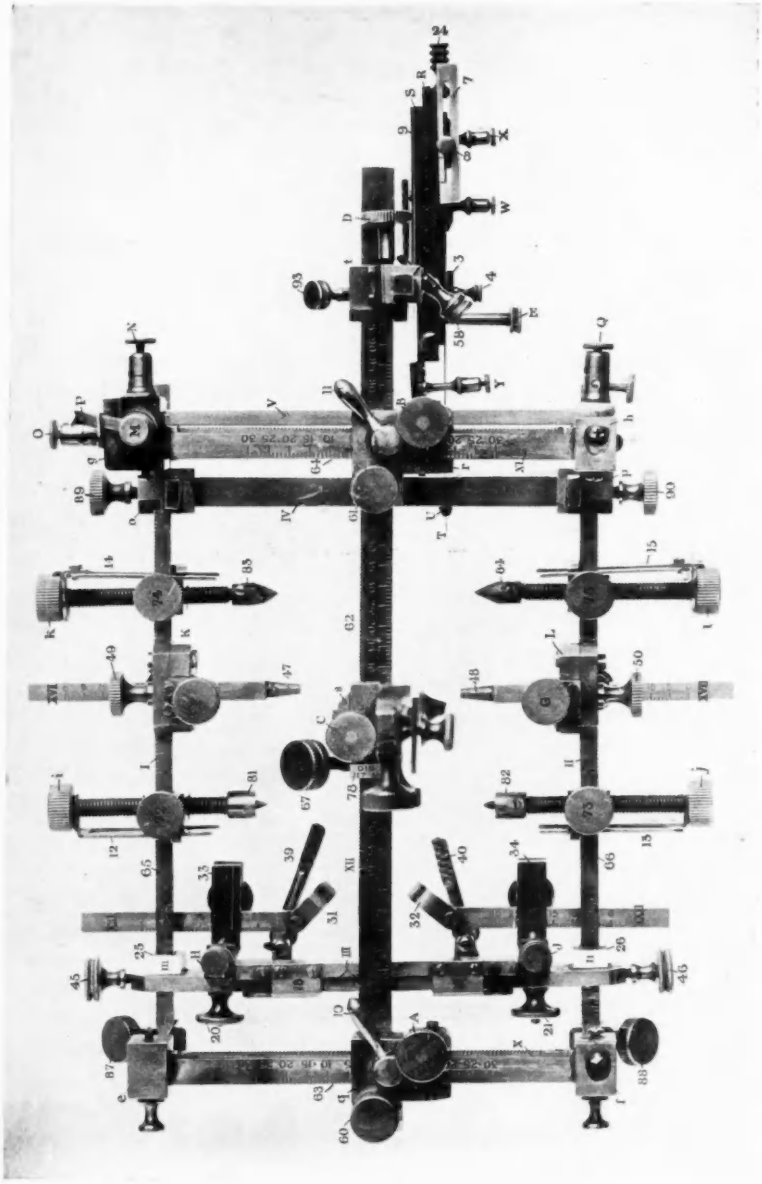

FIG. 6.

I.—*Clarke's stereotaxic apparatus for directing an insulated needle by graduated movement in three planes.*

I.—Plan.

No. I. Plan.—Roman Numerals.

I & II Right and left lateral bars of horizontal frame.
III Frontal bar, comprising nasal and orbital plates.
IV Occipital bar.
V Occipital stay.
X XI Anterior and posterior transverse guides.
XII Sagittal guide.
XVI XVII Right and left aural pivots, horizontal.
XXI XXII Right and left infra-orbital bracket bars.

Capital Letters.

A & B Anterior and posterior pinions for racking sagittal guide on transverse guides.
C Pinion for racking needle carrier on sagittal guide.
D Pinion for racking sheath on vertical guide.
E Pinion for racking bed of needle forward on sheath.
F G Right and left screws for aural adjustment of horizontal frame.
H J Right and left screws for orbital adjustment of horizontal frame.
K L Right and left aural adjustment fitting.
M Terminal for cathode lead from battery or coil.
N Terminal for cathode lead to needle.
O Terminal for cathode lead to live stop.
P Switch.
Q Terminal for anode leads, battery and needle.
R Vulcanite bed of needle holder.
S Sheath of needle holder.
T Needle.
U Stop.
W First needle terminal.
X Second needle terminal.
Y Live stop terminal.

Small Letters.

e f Right and left terminal joints of anterior transverse guide.
g h Right and left terminal joints of posterior transverse guide.
i j Right and left anterior lateral frame clamps.
k l Right and left posterior lateral frame clamps.
m n Right and left sliding joints of nasal plate.
o p Right and left sliding joints of occipital bar.
q r Two-way travelling joints of anterior and posterior transverse guides.
s Needle carrier travelling joint.
t Vertical guide two-way joint rack and slide.

Ordinary Numerals.

3 Vulcanite clamp on needle holder.
4 Screw for vulcanite clamp.
7 Adjustable index on bed of needle.
8 Screw for fixing index on bed of needle.
9 Millimetre scale on sheath graduated 40-0 mm.
10 & 11 Clamps to lock travelling joints on anterior and posterior transverse guides.
12 13 Millimetre scales on right and left anterior lateral frame clamps.
14 15 Millimetre scales on right and left posterior lateral frame clamps.
18 19 Right and left millimetre scales of orbital adjustment.
20 21 Right and left screws for fixing orbital adjustment.
24 Screw to adjust vulcanite bed for second needle.
25 26 Right and left bevelled edge indices on slots of nasal plate.
31 32 Right and left infra-orbital brackets.
33 34 Right and left sliding clamps for infra-orbital bracket bars.
39 40 Right and left horizontal maxillary rods.
45 46 Right and left screws for clamping sliding joints of nasal plate.
47 48 Tapered ends of right and left aural pivots.
49 50 Right and left fixing clamps of aural adjustment.
58 Clamp for fixing rack movement of vertical guide.
60 61 Right and left clamps to fix sagittal guide in longitudinal slots of travelling joints of transverse guides.

Ordinary Numerals (continued).

62 Millimetre scale on sagittal guide.
63 64 Millimetre scales on anterior and posterior transverse guides.
65 66 Millimetre scales on lateral bars of horizontal frame.
67 Clamp to fix travelling joint of needle carrier (vertical).
72 73 Right and left fixing screws for sliding joints of anterior lateral frame clamps.
78 Bevelled edge index of travelling joint of needle carrier for scale on sagittal guide.
81 82 Terminal points of right and left anterior lateral frame clamps.
83 84 Terminal points of right and left posterior lateral frame clamps.
87 88 Right and left anterior corner clamps for horizontal frame.
89 90 Right and left clamps for occipital sliding bar.
93 Clamp for posterior sliding joint on sagittal guide.

frame which coincide with the frontal section plane. When, therefore, the horizontal frame is accurately adjusted, by erecting two perpendiculars of equal length on the centres of the nasal and occipital bars and joining their upper and lower extremities with two straight lines, we can obtain a rectangular quadrilateral figure which represents the sagittal section plane. A similar figure representing the frontal section plane can be constructed from perpendiculars to the lateral bars which fall through the centres of the auditory meatus; in short, by the adjustment of the horizontal frame we secure data for constructing a rectilinear framework or cage corresponding to the three section planes of the head, which can be used for measurement and to direct a needle to any depth perpendicular to any section plane and at any distance from the other two, or, in other words, to any point of known distance from the three inner surfaces of any of the segments into which the head is divided by the three section planes.

These considerations show that the adjustment of the horizontal frame is of primary importance, and the means by which it is effected require some explanation. It has been mentioned that the base line is drawn through the middle of the lower margin of the orbit to the centre of the auditory meatus on each side and that the zero horizontal line is drawn parallel to the base line but at a convenient distance above it, namely, one-fourth of the height of the inter-aural frontal line. The adjustment of the horizontal frame to the zero horizontal plane is effected by two little pieces of mechanism called the aural and orbital adjustments, which enable the operator to bring the lower border of the horizontal frame to the correct height above the base line at these two points without difficulty.

(1) *The Aural Adjustment.*—In the illustration (fig. 7) two upright columns will be seen on the upper surface of the lateral bars. Each of them has a screw (G) at the top which raises and lowers a short vertical rod graduated in millimetres on its outer surface (XIX); this

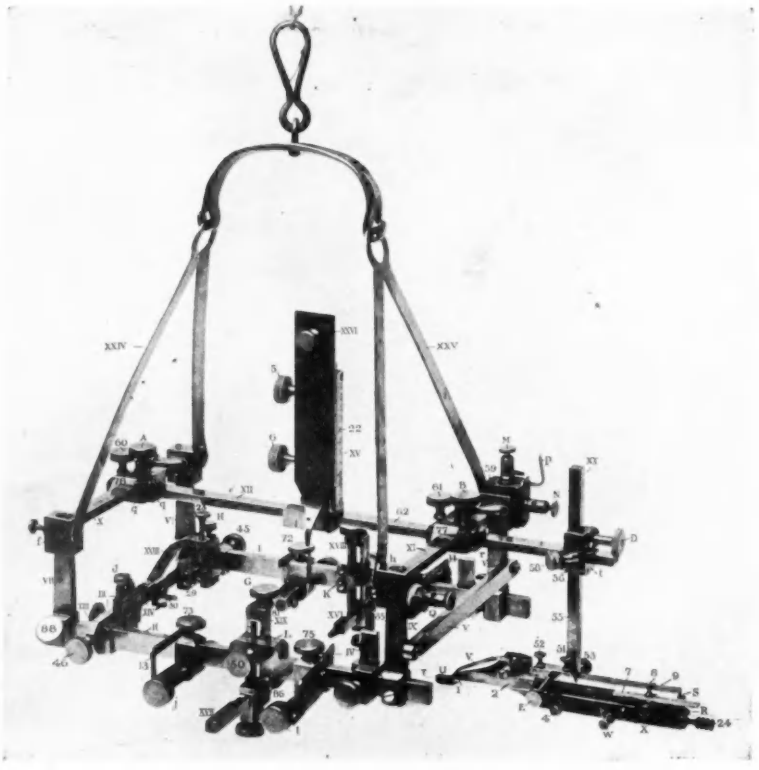

FIG. 7.

Side Elevation of Clarke's instrument.

Roman Numerals.

I II Right and left lateral bars of horizontal frame.
III Frontal bar.
IV Occipital bar.
V Occipital stay.
VI VII VIII IX Right and left anterior and right and left posterior corner columns.
X XI Anterior and posterior transverse guides.
XII Sagittal guide.
XIII Nasal plate.
XIV Orbital plate.
XV Needle carrier, vertical.
XVI XVII Right and left aural pivots, horizontal.
XVIII XIX Right and left aural pivots, vertical.
XX Vertical guides.
XXIII Supra-orbital stay.
XXIV XXV Anterior and posterior slings.
XXVI Dummy needle.

Capital Letters.

A B Pinions for racking sagittal guide on anterior and posterior transverse guides.
C Pinion for racking needle carrier on sagittal guide.
D Pinion for racking vertical guide.
E Pinion for racking needle bed on sheath.
G Screw of left aural adjustment of horizontal line.
H J Right and left screws of orbital adjustment of horizontal line.
K L Right and left aural adjustment fitting.
M Terminal for battery lead ; cathode.
N Terminal for needle lead ; cathode.
P Switch.
Q Terminal for battery and needle leads ; anode.
R Vulcanite bed of needle holder.
S Sheath of needle holder.
T Needle.
U Stop.
V Live stop.
W Needle terminal, first.
X Do. do. second.
Y Terminal for live stop.

Small Letters.

e f Right and left terminal joints of anterior transverse guides.
h Left terminal joint of post, transverse guide.
j Left anterior lateral frame clamp.
l Left posterior lateral frame clamp.
q r Two-way travelling joints on anterior and posterior transverse guide.
t Two-way joint rack and slide on vertical guide.

Ordinary Numerals.

1 Neck of sheath of needle holder.
2 Shoulder of sheath of needle holder.
4 Screw of vulcanite clamp on needle holder.
5 6 Screw for clamping needle holder in vertical carrier.
7 Adjustable index on bed of needle.
8 Screw for fixing adjustable index.
9 Millimetre scale on sheath of needle holder.
13 Millimetre scale on left anterior lateral frame clamp.
14 Millimetre scale on left posterior lateral frame clamp.
22 Millimetre scale on needle carrier.
23 Screw to depress forehead on supra-orbital brackets.
24 Screw to adjust sliding bed of second needle.
29 30 Right and left supra-orbital brackets.
45 46 Screws for clamping right and left sliding joints of nasal plate.
50 Fixing clamp of left aural vertical adjustment.
51 52 Screws for fixing needle pinion.
53 Screw for attaching needle holder to vertical guide.
55 Millimetre scale on vertical guide.
56 Bevelled edge of index millimetre scale of vertical guide.
58 Clamp for fixing rack motion of vertical guide.
59 Vulcanite insulator of cathodal terminal.
60 61 Clamps to fix sagittal guide in sliding joints of anterior and posterior transverse guides.
62 Millimetre scale on sagittal guide.
72 73 Fixing screws for sliding joints of right and left anterior lateral frame clamps.
75 Fixing screw for sliding joint of left posterior lateral frame clamp.
76 77 Bevelled edge indices for scales on anterior and posterior transverse guides.
81 Terminal point of right anterior lateral frame clamp.
85 86 Right and left slots for posterior lateral frame clamps for small animals.
88 Right and left anterior corner clamps for horizontal frame.

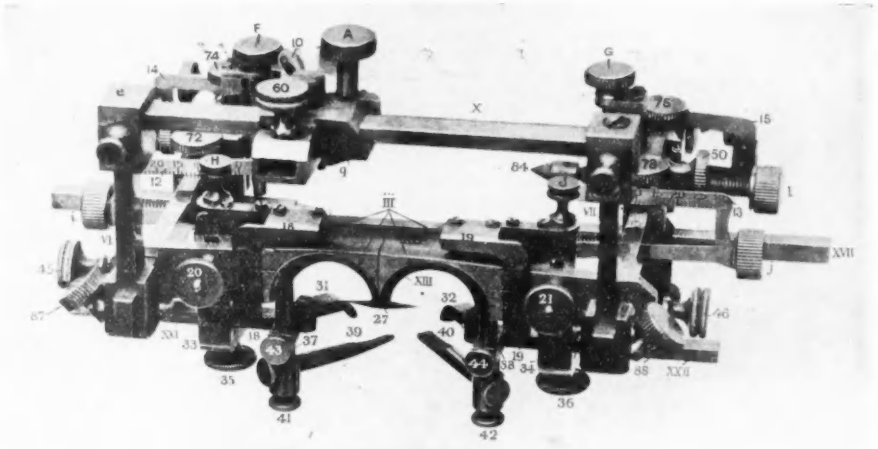

FIG. 8.

Front Elevation (anterior half) with orbital adjustment for various animals.

Roman Numerals.

III Frontal bar.
VI VII Right and left anterior corner columns.
X Anterior transverse guide.
XIII Nasal plate.
XIV Orbital plate.
XVII Left aural pivot, horizontal.
XXI XXII Right and left infra-orbital bracket bars.

Capital Letters.

A Pinion for racking sagittal guide on anterior transverse guide.
F G Screws for right and left aural adjustment of horizontal line.
H J Screws for right and left orbital adjustment of horizontal line.

Small Letters.

e Right terminal joint of anterior transverse guide.
i j Right and left anterior lateral frame clamps.
l Left posterior lateral frame clamp.
q Two-way travelling joint of anterior transverse guide.

Ordinary Numerals.

10 Clamp to lock travelling joint on anterior transverse guide.
12 13 Millimetre scales on right and left anterior lateral frame clamps.
14 15 Millimetre scales on right and left posterior lateral frame clamps.
18 19 Right and left millimetre scales of orbital adjustment.
20 21 Right and left screws for fixing orbital adjustment.
27 Needle indicating lower border of nasal plate, and therefore anterior limit of horizontal frame.
31 32 Right and left infra-orbital brackets.

Ordinary Numerals (*continued*).

33	34	Right and left sliding clamps for infra-orbital bracket bars.
35	36	Screws for clamping right and left sliding clamps for infra-orbital bracket bars.
37	38	Right and left vertical maxillary rods.
39	40	Right and left horizontal maxillary rods.
41	42	Screws for clamping right and left horizontal maxillary rods.
43	44	Screws for clamping right and left vertical maxillary rods.
45	46	Screws for clamping right and left sliding joints of nasal plate.
	50	Fixing clamp of left aural adjustment vertical.
	60	Clamp to fix sagittal guide in travelling joint of anterior transverse guide.
72	73	Right and left screws for fixing sliding joints of anterior lateral frame clamps.
74	75	Right and left screws for fixing sliding joints of posterior lateral frame clamps.
	84	Terminal point of left posterior lateral frame clamp.
87	88	Right and left anterior corner screws of horizontal frame.

is the vertical bar of the aural pivot. Its lower end terminates in a clamp which carries another graduated rod at right angles to it, the horizontal bar of the aural pivot (XVI XVII); this bar slides in the clamp perpendicularly to the sagittal plane and can be fixed by a screw in the clamp. Its inner extremity tapers slightly (fig. 6, 47) and fits accurately into the funnel of the ear plug. These conical plugs have been described on p. 57; they are fitted into the meatus, and the frame lowered over the head of the animal sufficiently to allow the horizontal aural pivots to engage the ear plugs. They are pushed into the funnels to exactly the same distance measured by the millimetre scales on the horizontal bars of the pivots, and when these are the same length they are fixed by the screws. Thus in practice these are the first lateral adjustments made, and by their equality these pivots first approximately centre the head in the sagittal plane. If the height of the horizontal line above the base line is known—suppose it is 10 mm.—the vertical aural pivot bar is set at 10 mm. by its scale and screw, and this brings the lower border of the frame 10 mm. above the centre of the meatus; but generally the height of the vertex above the meatus is not known and has to be measured in the apparatus, and the first adjustment of the vertical height of the aural pivots is only approximate and provisional. The measurement of the frontal line is made by provisionally fixing the aural pivots at 10 mm. and then dropping a dummy needle (fig. 7, XXVI) vertically by the needle carrier (fig. 7, XV) on to the vertex. The scale on the needle carrier gives the distance from the vertex to the horizontal plane, and this, plus the provisional setting of 10 mm., gives the whole height. If this exceeds or is less than 40 mm. then corrections are made accordingly in the aural and orbital adjustments (*see* figs. 5 and 7).

(2) *The orbital adjustment* for the monkey is somewhat different from that which is employed for other animals, and will be described first.

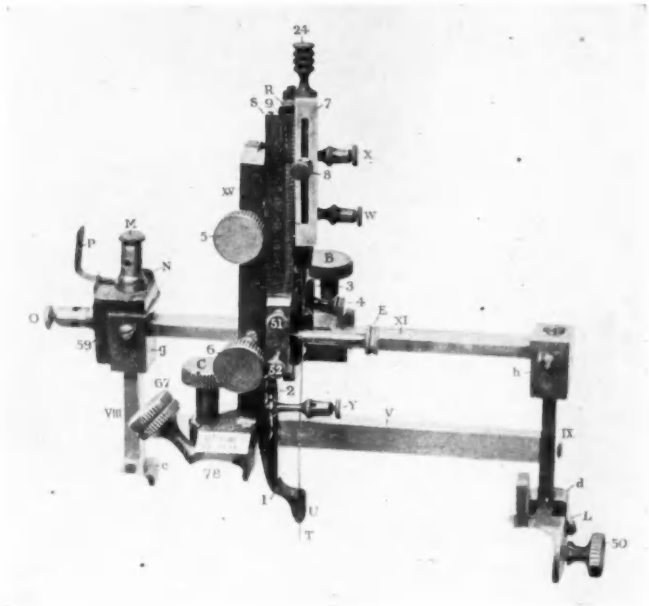

FIG. 9.

Front Elevation (posterior half), with needle mounted for vertical insertion.

Roman Numerals.

V Occipital stay.
VIII IX Right and left posterior corner columns.
XI Posterior transverse guide.
XV Needle carrier, vertical.

Capital Letters.

B Pinion for racking sagittal guide on posterior transverse guide.
C Pinion for racking needle carrier on sagittal guide.
E Pinion for racking bed of needle holder in sheath.
L Left aural adjustment fitting.
M Terminal for battery lead; cathode.
N Terminal for needle lead; cathode.
O Terminal for live stop lead; cathode.
P Switch.
R Vulcanite bed of needle holder.
S Sheath of needle holder.
T Needle.
U Stop.
W Terminal of first needle; anode.
X Terminal of second needle; cathode.
Y Live stop terminal.

Small Letters.

c d Right and left posterior corner joints of horizontal frame.
g h Right and left terminal joints of posterior transverse guide.

Ordinary Numerals.

1 Neck of sheath of needle holder.
2 Shoulder of sheath of needle holder.
3 Vulcanite clamp on bed of needle holder.
4 Screw for clamp on bed of needle holder.
5 6 Screws for clamping needle holder in vertical carrier.
7 Adjustable index on bed of needle.
8 Screw for fixing index on bed of needle.
9 Millimetre scale on sheath of needle holder.
24 Screw to adjust sliding bed for second needle.
50 Fixing clamp for left aural adjustment.
59 Vulcanite insulator of cathodal terminal.
67 Clamp to fix travelling joint of needle carrier.
78 Bevelled edge index on travelling joint of vertical needle carrier for scale on sagittal guide.

The front of the horizontal frame is formed by the frontal bar, which consists of two thin plates, one in front of the other, and held together by two screws (fig. 10, 20 21). They are called nasal (the front one, XIII) and orbital plates (the rear one, XIV) respectively; their connection permits a vertical sliding movement between them, regulated by the screws (fig. 10, H J) and indicated by the millimetre scales (18-19) on the face of the nasal plate. The latter is extended laterally and slotted near its extremities, which thus form sliding joints on the lateral bars (fig. 10, m n). As the upper surfaces of these latter are graduated in millimetres backwards and forwards from a point opposite the centre of the auditory meatus, which is marked zero (and the posterior edges of the slots are bevelled as indices), the distance of the posterior surface of the orbital plate from the inter-aural frontal line is read off at once. The orbital plate is brought into contact with the forehead by sliding the whole adjustment backwards on the lateral bars, to which the nasal plate is fixed by the clamping screws as described (fig. 10, 45 46). The lower border of the nasal plate, of course, has, with the rest of the horizontal frame, to coincide with the horizontal section plane. This is effected as follows: Where the orbital plate is in contact with the forehead there are attached to it on each side small horizontal slightly convex plates, the superior orbital brackets (fig. 10, 29-30), which project backwards about 6 mm. beneath the supra-orbital arches. An arm (XXIII), the "supra-orbital stay," which extends back about 2 cm. over the forehead and carries a vertical screw (fig. 10, 23), affords a simple means by which the supra-orbital arches are kept in contact with the orbital brackets on which they rest. The brackets and stay, therefore, like the blades of a pair of forceps, hold the frontal bone to the orbital plate, and the vertical movement and millimetre scales between this and the nasal plate enable the operator to see and regulate the height of the supra-orbital arch above

the lower edge of the horizontal frame, *i.e.*, of the nasal plate. As the vertical diameter of the orbit is taken beforehand with callipers (in the average Rhesus, as already stated, it is 20 mm.), if the distance of the edge of the frame below the supra-orbital arch is known its distance above the lower margin of the orbit is known also. The lower border of

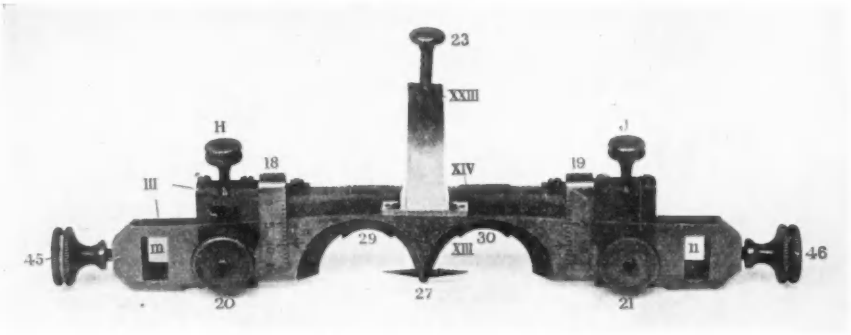

FIG. 10.

Orbital Adjustment for Monkey.—Front Elevation.

Roman Numerals.

III Frontal bar.
XIII Nasal plate.
XIV Orbital plate.

Capital Letters.

H J Right and left screws for orbital adjustment of horizontal frame.

Small Letters.

m n Right and left sliding joints of nasal plate.

Ordinary Numerals.

18 19 Right and left millimetre scales of orbital adjustment of horizontal frame.
20 21 Right and left screws for fixing nasal and orbital plates.
23 Screw to depress forehead.
27 Needle indicating lower border of nasal plate, and therefore horizontal frame.
29 30 Right and left supra-orbital brackets.
45 46 Screws for clamping right and left sliding joints of nasal plate.

the horizontal frame is therefore made to coincide with the horizontal section plane at the specified height (one-fourth of the frontal line) above the lower margin of the orbit by the screws (fig. 10, H J) and then fixed by the screws (20 21). The orbital adjustment being thus completed, the bevelled edges (fig. 6, 25 26) behind the nasal bar slots will

now on the average read 47 mm. on the pre-aural scales of the lateral bars on both sides, and the nasal plate is fixed by the screws (fig. 10, 45 46). The occipital bar (fig. 6, IV) is next brought forwards into contact with the occiput, the bevelled edges of its sliding joints (fig. 6, o p) reading on the average 33 mm. on the post-aural scale of the horizontal frame bar, and it is also clamped.

The scale of the aural (fig. 7, XVIII XIX) adjustments is set at 10 mm. (if this be one-fourth of the frontal line), and then the four lateral frame clamp points (fig. 6, 81 82, 83 84) are screwed in sufficiently to secure the head firmly in its position. Each clamp is provided with a millimetre scale to ensure that the corresponding pairs, pre-aural and post-aural, are screwed into the same distance on each side. Since the same precaution was observed in adjusting the aural pivots the sagittal centreing of the head is adequately provided for by these six lateral supports thus accurately measured to corresponding lengths. After the clamping points have been fixed the occipital bar can be removed to give free access to the cerebellum. The horizontal frame has thus been accurately adjusted so that its lower border coincides with the zero horizontal line, and it now constitutes the foundation of a frame which corresponds with the three section planes and provides for directing a needle by them. Before describing the needle mechanism a few words are required on the adjustments for various other animals besides monkeys and on corrections for size, for hitherto we have only considered the average rhesus. As the measurement of the head in the apparatus, in correcting for size, &c., involves the use of some parts which have not been described it will be best to complete the description of the instrument and then consider the remaining questions of measurement.

Adjustment for animals below primates.—The instrument can be applied to any moderately sized mammals and to the larger birds, such as geese and ducks. We have not attempted to enlarge it so as to include dogs because in almost every respect the cat's brain is superior to the dog's for elementary neurological purposes; the nerve tracts are better marked, the size of the encephalon is more convenient for serial sections, and, most important of all, cats' heads are of much more uniform size and shape than those of dogs; in fact, the endless variations in the size and shape of dogs' heads make them unsuitable for a research involving accurate cranio-encephalic topography. The orbital adjustment is the only one that needs modification to suit the heads of animals below the primates, for in all cases the range of movement in other parts of the apparatus is sufficient for any variation of size that is required, the aural

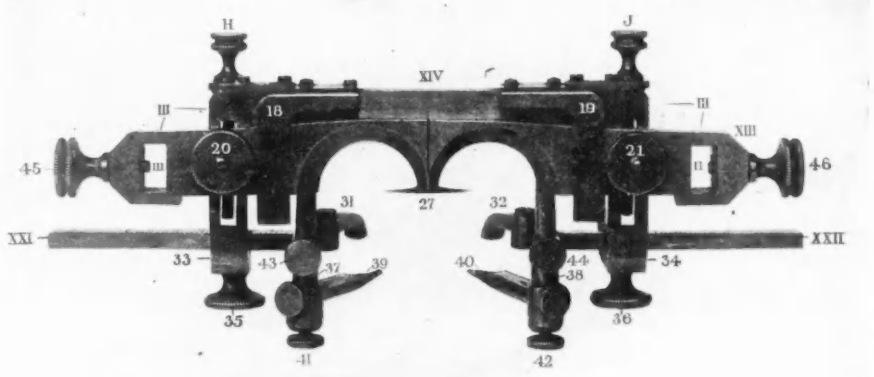

FIG. 11.

Orbital Adjustment for various Animals.—Front Elevation.

Roman Numerals.

III Frontal bar.
XIII Nasal plate.
XIV Orbital plate.

Capital Letters.

H J Right and left screws for orbital adjustment of horizontal frame.

Small Letters.

m n Right and left sliding joints of nasal plate.

Ordinary Numerals.

18 19 Right and left millimetre scales of orbital adjustment of horizontal frame.
20 21 Right and left screws for fixing nasal and orbital plates.
27 Needle indicating lower border of nasal plate, and therefore horizontal frame.
31 32 Right and left infra-orbital brackets.
33 34 Right and left sliding joints for infra-orbital bracket bars.
35 36 Right and left screws for fixing sliding joints (33 34).
37 38 Right and left maxillary rods, vertical.
39 40 Right and left maxillary rods, horizontal.
41 42 Right and left screws for clamping horizontal maxillary rods.
45 46 Right and left screws for clamping sliding joints of nasal plate.

adjustment fitting the form of ear plug which may be required for any species of animal.[1]

Though the modification of the orbital adjustment we suggest as more useful[2] for animals below the monkey looks different (*see* fig. 11),

[1] It should be mentioned that in the cat the orifice of the meatus is so covered by the pinna that division of the latter is necessary to admit the ear plugs; the incision should be made in the line of the postero-inferior edge of the tragal portion of the pinna.

[2] Possibly for any species.

anyone who has followed the description of the adjustment for the monkey will find the principle the same and the modifications easy to understand. The head, and therefore the lower border of the orbit, is raised and lowered in relation to the lower border of the frame (*i.e.*, of the nasal plate, fig. 11, XIII) by a vertical sliding motion between the nasal and orbital plates regulated by screws (fig. 11, H J) and indicated by millimetre scales (fig. 11, 18 19) on the face of the nasal plate—all this is the same in plan as before. The only difference is that while the orbital plate is connected to the forehead of the monkey by the superior orbital brackets and stay, which grasp the frontal bone like the blades of a pair of forceps, in this pattern the orbital plate is attached to the superior maxilla by inferior orbital brackets (fig. 11, 31 32) and horizontal maxillary bars (39-40). The former project a few millimetres into the orbit over its lower edge, the latter similarly into the mouth, and both together hold the superior maxilla, grasping it like a pair of forceps by the lower edge of the orbit and the upper teeth. In birds the horizontal maxillary bars pass under both mandibles instead of between them. The maxillary bars consist of vertical (fig. 11, 37 38) and horizontal (39 40) portions freely adjustable in all directions; they and the orbital brackets are supported on graduated arms (fig. 11, XXI XXII), supported and sliding in clamps (fig. 11, 33 34) which allow them a transverse motion; the clamps are fixed to the orbital plate, and thus, being attached to the nasal plate, have a longitudinal motion on the lateral bars. Both infra-orbital brackets and maxillary bars have therefore a transverse and longitudinal movement by which they can be adjusted to heads of any size.

Mechanism for Directing the Excitation or Electrolytic Needle.

We have pointed out the data for the mechanical direction of a needle in any plane by the adjustment of the horizontal frame, and the illustrations (fig. 6 and 7) show how one method of giving effect to the principles of localization we have described are carried out in the instrument. Four rigid perpendiculars, the corner columns (fig. 7, VI VII VIII IX), are fixed to the corners of the horizontal frame and joined in pairs by two transverse graduated bars, the anterior and posterior transverse guides (figs. 6 and 7, X XI); the centre of each bar corresponding to the median sagittal plane is marked zero and graduated in millimetres from that point on each side. Each transverse guide carries a travelling two-way joint (figs. 6 and 7) with rack and pinion motion.

These joints travel on the transverse guides and at the same time support and carry with them a long graduated bar, the sagittal guide (figs. 6 and 7, XII). This bar is fixed in the slots of the two-way joints in such a position that the zero marked on it corresponds to the inter-aural frontal line, and the sagittal guide is graduated forwards and backwards from this point. The only movement of the sagittal guide is a lateral one, by means of the travelling joints on the transverse guides; longitudinally it is a fixed base on which the arm carrying the horizontal needle slides by a simple joint and on which also the vertical (*see* fig. 7, XV) needle carrier connected perpendicularly to it by a travelling joint moves forwards and backwards from the zero inter-aural frontal plane. The excursions of the needle carriers are indicated by the millimetre scale on the sagittal guide.

The Needle Holder and its Movements.

(1) The needle, which may be single or double, consists of an iridio-platinum wire insulated nearly to the point in a capillary glass tube, and is clamped on a vulcanite plate, the bed. The glass is held by a vulcanite clamp, from which it is separated by a small piece of soft rubber. The proximal end of the projecting wire is fixed in a metal clamp secured by the terminal, which is screwed firmly down upon it, and electrically connects the needle with the lead from the coil or battery as the case may be. The bed slides by a bevelled edge on each side on a sheath, which tapers in front into a shoulder and neck, and the latter terminates in a small flattened vulcanite cylinder, the stop, perforated to permit the passage of the needle, which can be advanced and withdrawn through the stop by a rack and pinion movement of the bed on the sheath, registered by an adjustable index on the bed, and a graduated millimetre scale on the sheath. This gives the needle an excursion of 40 mm. The perforation in the stop is formed by a lateral slit open on one side to admit the needle and then closed by a fine brass rod which projects a little beyond the stop, and at its proximal end is attached to the shoulder of the sheath by a terminal which receives a lead if required and makes contact with the rod; this rod then constitutes what we call a "live stop," and may be used for so-called unipolar excitation. It also serves the purpose of exercising slight pressure on the needle in its groove, steadying it, and serves as an electrode when required. It is convenient when a single wire is employed. As we show later, in deep punctures faradization of the brain by a long arc stimulation is highly objectionable,

since if one electrode is formed by a needle point and the other by some form of surface contact the current traverses many excitable areas and may produce confused and misleading results, but in making electrolytic lesions the single needle is almost indispensable, and as we never electrolyze without at least one faradic excitation, and generally several, the difficulty is to get a satisfactory stimulation when the single needle is used. It was to meet this that the "live stop" was devised, and in practice we find that as it makes a small surface contact close to the needle, the current is notably confined to its track, thus very much diminishing the escape of current and irregular effects of wider and more distant surface contacts. The disadvantage electrolytically is the exaggeration of the needle track.

The essential parts of the needle holder are thus the bed and the sheath, the latter including the neck and stop. As the needle is carried forwards through the stop the adjustable index attached to the bed indicates the excursion of the needle on a scale on the sheath, which is so graduated that as the needle is advanced the index approaches zero. The object of this is that as the needle penetrates the brain perpendicular to either the horizontal or frontal zero section planes, it is convenient that the index should arrive at zero when the point of the needle reaches the zero plane.

The instrument is constructed to direct the needle at will into any part of the brain from two positions: (1) Vertical from above, and (2) horizontal from behind.

(1) In the vertical position the sheath of the needle bed slides in a slot in the carrier, where it can be fixed with two screws. It is perpendicular to the sagittal guide, and, of course, to the horizontal section plane. It has been explained that the carrier travels longitudinally on the sagittal guide from a zero, which corresponds with the inter-aural frontal section plane, and laterally on the transverse guides to right and left of the median sagittal plane. By these two movements the needle can be brought over any square millimetre in the horizontal plane. For the vertical movement the connection between the sheath and the carrier is used as a coarse adjustment. For this purpose there is a scale on the carrier and an index on the sheath (figs. 9 and 7). The scale is originally graduated as follows: The sheath is pushed downwards till the distal surface of the stop is level with the lower border of the horizontal frame. This point is marked zero on the scale, and the graduation is made as the sheath is drawn up. This scale therefore always indicates in millimetres the distance of the stop above the

zero horizontal line. In use the sheath is pushed down till the stop is at a convenient point, commonly the surface of the brain, and it is fixed there; the scale on the carrier (XV) then shows how many millimetres separate the stop from the horizontal line. The needle is then advanced till its point is exactly flush with the surface of the stop, and the adjustable index on the bed is set at the same figure on the scale on the sheath. If the stop, according to the scale on the carrier, is 30 mm. above the horizontal line, and the ivory index is set at 30, then as the needle penetrates the brain the figure on the sheath scale will always show the distance of the point from the horizontal section plane, and when it arrives there the index will be at zero.

(2) In the second or horizontal position the needle holder is connected to the sagittal guide in a different way. In the illustration it is shown connected to the hinder end of the sagittal guide as follows: The sheath carrying the bed and needle is fixed at right angles to the lower end of a vertical guide (fig. 7, XX) by two screws (fig. 7, 53). The vertical guide is connected with the sagittal guide by a two-way joint; one slot of which (horizontal) slides over the sagittal guide and can be fixed at any point by a screw (fig. 6, 93). The other slot of the joint is vertical and the vertical guide is worked up and down in it by a rack and pinion (fig. 7, D). The vertical guide is graduated in such a way that when the point marked zero is opposite the bevelled edge of the joint (fig. 7, 56) which serves as the index, the needle is on the horizontal line, and the graduations above and below zero show the vertical distance of the needle above or below the horizontal line.

The transverse movements of the sagittal guide to right and left of the median sagittal plane convey the same motion to the needle, and the vertical and sagittal guides in this way afford the two movements required to bring the needle opposite any square millimetre on the frontal plane. The third movement, that of the needle towards the frontal plane, is a double one as in the first position, but differently arranged. The coarse adjustment is the movement of the whole needle holder and stop towards the frontal section plane. This is effected by the sliding joint (fig. 6, t) on the sagittal guide. The bevelled edge of the joint is an index for the graduated scale on the guide and indicates the distance of this edge from the interaural plane, *i.e.*, zero on the sagittal guide. The distal surface of the stop (U) is 50 mm. in front of the bevelled edge. As the distance of the bevelled edge from the frontal line is known, that of the stop from this line is known also. For example, if the bevelled edge is at 80, the anterior surface of the stop

is 30 mm. behind the frontal section plane. The point of the needle is racked flush with the surface of the stop and the adjustable index (fig. 6, 7) set at 30. As the needle advances towards the frontal line the index travels towards zero on the scale on the sheath (fig. 6, 9), and when it reaches zero the point of the needle arrives at the zero frontal inter-aural plane.

Needles.—These are made of iridio-platinum (20 per cent. iridium), about 10 cm. long, pointed and of various calibres, according to the size of the electrolytic lesion required, which depends on various considerations. For stimulation fine needles are required (30 to 32 on the English standard wire gauge), about 0·22 mm. in diameter; they are fitted into the smallest glass tubes which will take them, about 25 to 26 gauge. We have not found it desirable to use finer needles than this as a rule. In every excitation experiment there are some points which must be marked by a small electrolysis, sometimes to record a noteworthy response, and in any case to serve as indicators to verify or correct the position of the part investigated after the brain has been fixed and sectioned. Owing to the high resistance, however, there is a limit to the calibre of needles which can be employed with advantage for electrolysis. Illustrations of the needles which we are at present using, and showing both the actual size and enlargement, are given in fig. 12. They represent three varieties: the single, the double-barrelled, and the concentric. In all cases the insulation is by a capillary glass tube. The following are measurements of needles in use at present showing the relations of needles and glass tubes. The measurements are given in millimetres and in the English standard wire gauge:—

	Wire gauge	mm.		Wire gauge	mm.
1 Single needle, fine ...	32 ...	0·19 ...	Glass tube ...	27 ...	0·34
2 Single needle, large ...	25 ...	0·45 ...	Glass tube ...	21 ...	0·70
3 Double barrel ...	30 ...	0·27 ...	Glass tube ...	24 ...	0·50
	30 ...	0·27 ...	Glass tube ...	24 ...	0·50

The single needle is the most convenient when only an electrolytic lesion is required; it gives a better point, is most easily introduced, with the least effect on the tissues, its track being scarcely recognizable in sections; its size and the amount of platinum exposed are very easily regulated and consequently the size of the lesion; the latter, when the needle is an anode, is generally spherical, circumscribed and precisely defined. For preliminary stimulation to verify the position, &c., of the

needle, it is best to employ it with the live stop, but this must not, of course, be used for any subsequent electrolysis or it will produce a kathodal lesion on the cortex. When stimulation is the principal object a single needle is undesirable, since even the live stop gives too large an area of excitation, and a short arc stimulus is far more satisfactory. Either the double-barrelled or concentric needle shown in fig. 12 may be used for short arc stimulation. The double-barrelled needle penetrates well, makes a small wound and has good rigidity. It was a

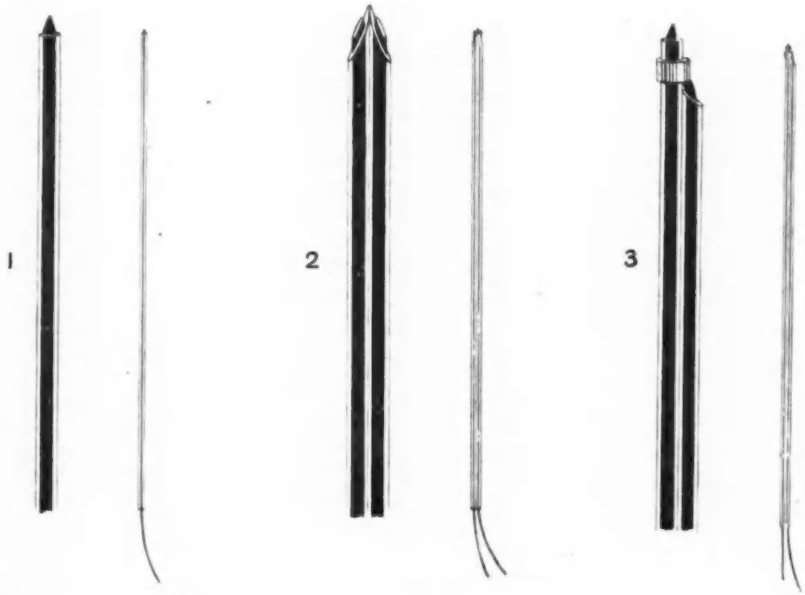

FIG. 12.

Iridio-platinum needles insulated in glass tubes.

1 Single needle. 2 Double-barrelled needle. 3 Concentric needle.
(Actual size and enlarged.)

long time before we succeeded in getting two capillary glass tubes fused together, and we have to thank Professor Jackson, of King's College, for the suggestion which made it practicable. This was to fuse two ordinary glass tubes together for a short distance, and then

heat them and draw them out together. This gives excellent results; the tubes are fused together like the barrels of a gun and can be drawn out quite straight and as long and fine as can be wished. They are ground to a point and wires inserted, which are cut parallel to the slanting orifice which terminates in the point. The ends of the wires are thus separated completely from one another by a glass point, round the edge of which the current must pass.

The concentric needle gives the most constant effects, especially where groups of cells in a nucleus are stimulated. It is rather difficult to make, and, unless very well finished, is rather clumsy, less easy to introduce, and makes a larger track than the others. Mr. Rittershaus,[1] who makes them for us, has much improved them, and is now making them with the double-barrelled glass sheath which diminishes these drawbacks. As will be seen from the illustration, they consist of two fine single insulated needles. The wire of one projects about 0·75 mm. beyond the glass, while of the other the wire is drawn out of its glass tube sufficiently to make a little collar round the glass of the first about 0·75 mm. behind the edge of the glass. The end of the needle, therefore, consists of wire, glass, and collar, each 0·75 mm., or about 2 mm. in all, and the current flows backwards and forwards from the point all round to the collar, giving an equally diffused stimulus for a small area round the point of the needle. When an electrolysis is required the point or the collar can be used alone, the point making a very minute, the collar a moderate-sized, and both together a large lesion.[2]

Corrections for Size and Symmetry.

In describing the adjustment of the instrument to the head of the rhesus it was assumed that the animal was a typical example of average measurements. In practice there are nearly always some variations, and they may be considerable; every head, therefore, must be carefully measured and corrections made for irregularities. The procedure we have adopted is as follows: We first take the maximal longitudinal and transverse diameters of the cranium, *i.e.*, above the level of the zygomatic arch as well as the greatest vertical diameter of the orbit, with callipers before applying the instrument; an outline drawing of the head is made to scale on millimetre paper, and all the measurements filled in as they

[1] Of Huntley Street, Tottenham Court Road.
[2] Mainly kathodal.

are taken (*see* specimen of such outline, fig. 5). The callipers are necessarily not as accurate as the apparatus, and the preliminary measurements with them are checked by reading on the instrument after the head is fixed. The measurements, including the true height (fig. 5, I and II) of the horizontal line shown in the outline sketch, are all filled in, and a chart frozen section which shows the required lamella is selected, and the dimensions of each segment in the experimental animal and the chart section compared. If the error of difference is less than 10 per cent., we usually treat it as negligible, but if it amounts to 1 in 10 or more we make the necessary correction according to a table of equivalents. With such corrections and careful adjustment of the apparatus the results are generally accurate in the rhesus. If there is a great difference between the absolute dimensions of the animal's head and the chart section, there is, of course, more likelihood of error, but discrepancies can be in a great measure avoided; thus if there is only one series of frozen sections to work by, animals must be selected which approach it in size, and, of course, if two or three series of sections of different sized animals are available the operator is less restricted. On the question of symmetry the measurements depend on the assumption that the positions of the bony landmarks, *i.e.*, the meatus and orbits, are generally symmetrical. Moderate variations of proportional measurement can be corrected, and though, of course, the fewer such necessary amendments are the better, they are not necessarily inconsistent with accuracy provided they balance, but an irregularity which prevents the inter-aural plane being perpendicular to the sagittal plane is a grave fault. We do not find that such serious forms of asymmetry occur in monkeys. Of other animals we cannot speak from much experience, but cats' skulls are less regular than monkeys, and more care will be necessary in their selection.

Asepsis.

It is hardly necessary to say that in degeneration experiments every care to maintain asepsis must be observed. It need not be alluded to further here except in relation to the instrument; this is too delicate to bear repeated boiling, and as some portions of it are of vulcanite efficient sterilization by heat is precluded. We keep the whole instrument in absolute alcohol, which does not injure it and has proved satisfactory. The glass and platinum needles are easily sterilized in strong acids. The small wounds and the protection from contact afforded by the instrument are very favourable to asepsis and infection ought not to occur.

Preparation of Tissues.

As Marchi's method is so well known and described in text-books we need not do more than mention a few points. We inject the brain of the animal just killed, from the aorta preferably, with Müller's fluid (or Müller and formalin) and preserve in Müller alone, since we think any continued use of formalin interferes with osmic acid staining. It is very desirable when employing this method to cut the brain parallel to the section planes which have been defined in the use of the apparatus (*vid. inf.*), and such section blocks should never be more than 2 mm. thick, cut as soon as the brain is fixed.

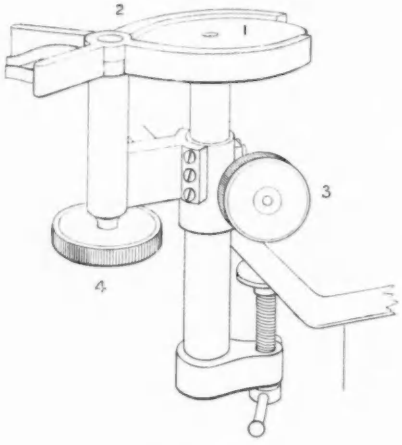

FIG. 13.

Macrotome for cutting brain in slices of known thickness.

1 Plate, raised or lowered by pinion 3.
2 Jaws.
3 Rack and pinion movement to raise and lower plate 1.
4 Clamp to fix jaws 2.

Macrotome.

An illustration is given in fig. 13 of a section instrument, or macrotome, which is useful for this purpose. The brain is divided in one of the section planes. The cut surface is then applied to the plate (1), and the jaws (2) adjusted 2 mm. above the plate. While the brain is well moistened with water, successive slices are cut with a brain

knife, keeping the edge of it on the jaws with a short sawing movement. In the sagittal plane the median section can be judged by the eye, but for the other two planes it is necessary to mark the brain; at present the only way of doing this accurately is to adjust the head in the stereotaxic instrument and mark it before it is removed. Thus when it is in the instrument four to six points can be marked by the dummy needle on both sides of the head in either frontal or horizontal planes (preferably in the inter-aural plane); the skull is removed or drilled at these points and the brain marked with a red-hot needle. After the brain, removed from the skull, has been suspended by Retzius's method in Müller's fluid for twenty-four hours, the desired section can be carried through these marks.

We will now proceed to discuss the electrolytic lesion as produced by the instrument just described, and next the procedure of stimulation, since the use of these methods led us to consider and experimentally investigate a number of points of procedure which bear directly on the question of the accuracy to be obtained in all investigations of this kind.

Although a natural order of these two subjects would be (1) stimulation, (2) electrolysis, for that is our experimental procedure, it will be more convenient historically to deal first with the application of electrolysis to the production of localized lesions in the encephalon.

IV.—The Electrolytic Lesion.

Historical References.

Attention was early directed to the electrolytic method; thus Mr. William Brande, Sir Everard Home, and Sir H. Davy in the *Philosophical Transactions of the Royal Society* for 1809, give an account of some experiments on the electrolysis of animal fluids undertaken by Mr. Brande for Sir Everard Home. In some of these experiments Mr. Brande was assisted by Sir H. Davy.

Various albuminous fluids were employed, including blood and serum, the former of these being in one experiment contained in the vessels of a freshly killed deer.

The general results may be summarized by saying that with strong currents there was always rapid coagulation at the kathode, none with weak currents. With both currents there was slight coagulation at the anode. Davy's explanation of this was that the albumen was kept in solution by alkali, and when this was liberated coagulation of the

albumen followed. Brande showed that while strong currents are required to liberate the alkali sufficiently to coagulate the albumen, there is more tendency for slight coagulation to occur at the acid pole with weak currents. With fresh human blood kept at 100° F. and a current from twenty 4 in. double plates employed for fifteen minutes, there was no coagulation nor any change, but a slight difference of colour and the production of acid and alkali at the electrodes.

In experimenting on deer's blood in a blood-vessel, and with serum, strong currents caused a rapid coagulation at the kathode, but a slow and slight deposit of albumen at the anode. Employing a weak current for fifteen minutes, a filament about $\frac{1}{4}$ in. long was seen adhering to the positive wire, but nothing at the kathode.

Thus the existence of polar differences in the establishment of a coagulation necrosis have long been known. The direct use of electrolysis as a method of causing localized lesions in the central nervous system seems to have been first described by J. Sellier and H. Verger (1898), who produced electrolytic lesions of the thalamus in five dogs with two insulated needles. A current of 9 ma. to 12 ma. being employed for from seven to ten minutes, the lesions obtained were about the size of a pea or grain of maize.

Gustave Roussy [17] also produced a lesion of the thalamus in two cats, two dogs and one monkey. Following the method of Sellier and Verger, he gives a more precise description of the procedure he employed as follows:—

Current.—A battery of 20 elements with galvanometer in circuit using 8, 10, 12 ma., for eight or ten minutes.

Needles.—Iridio-platinum sheathed in glass. Wire not exceeding 8 cm. long, 0·3 mm. calibre and 1 mm. exposed. They were mounted on a vulcanite plate to carry terminals, one in a slot so that the needles could be separated or approached.

The resistance was observed to fall during the passage of the current (*vide* p. 97 in present paper for reference to this point). The circuit was opened and closed by degrees to avoid movements of the animal.

Roussy reached the thalamus in the cat and dog by taking the middle point of the median sagittal line, *i.e.*, a line extending from the superciliary ridge to the occipital protuberance and trephining $\frac{1}{2}$ cm. to 1 cm. behind this point.

Owing, however, to unavoidable want of precision in this method of localization, Roussy found that of twenty experiments, but five, *i.e.*, one-fourth, were available for the research.

Roussy states that Golsinger, of St. Petersburg, in 1895, was the first to employ this method for destruction of the deep tissues of the brain. He used or advocated unipolar electrolysis, one pole being connected with an insulated needle in the brain, the other attached to an indifferent plate electrode on the abdomen. The current he employed varied from 20 to 40 ma., and, according to his measurements, 8 coulombs gave a lesion the size of a pin's head, 36 coulombs a lesion the size of a cherry. Golsinger showed at the Conférence des Médecins de la Clinique des Maladies Nerveux et mentals (St. Petersburg, 1895), the brains of six dogs with isolated lesions produced by this method. Unfortunately we have not been able to see the report of this communication.

Production of the Electrolytic Lesion.

Having determined on electrolysis as the control to electrical excitation we began by investigating the effects of the various forms of electrical currents on the central nervous (cerebral) tissue, and we arrange the results obtained as follows :—

(A) The Lesion as Produced by Sparks from High Tension Currents.

We first endeavoured to obtain lesions by the use of sparks from high tension currents with an interruption of about 100 per second. The electrolytic action of such sparks on water (steam) has been investigated since Perrot's original observations and has received thorough reinvestigation by Professor J. J. Thomson [23] and others. Lesions of the brain so produced we have found to consist of combined electro-thermic, electro-chemical and mechanical effects.

When two needles, 4 mm. apart, were introduced into the cerebral substance to a depth of 5 mm. and the coil started, the result was to cause a rapid swelling and illumination of the superjacent cortex by reason of the passage of sparks causing practically a subcortical deflagration. Macroscopically and microscopically the resultant lesion proved to be a combined laceration and cauterization with no determinate border. The site of one needle pole was crateriform and empty, that of the other was more tubular and filled with gas bubbles, which were present in a diminishing degree along the narrow line of destruction which marked the shortest paths between the needle points.

The restriction of the effects of such a lesion was proved as in the case

shown in fig. 14, for, on faradic excitation, the excito-motor cortex immediately in front of the destroyed area was found to be physiologically active close up to the margin of the lesion.

Although the combined effect was thus fairly localized it appeared to us that the degree of destruction by sparks is not sufficiently controllable to be useful for our purpose and we gave it up on this ground.

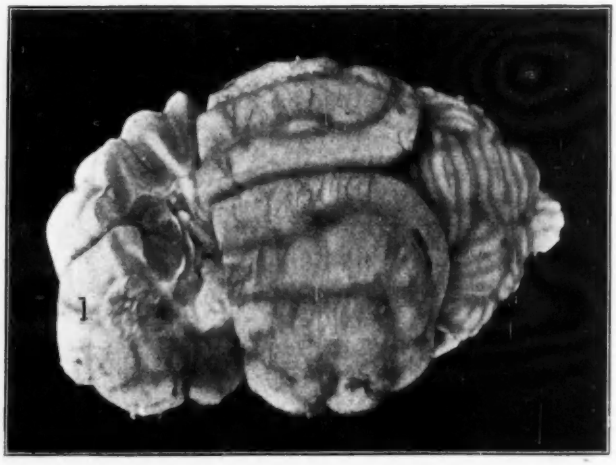

FIG. 14.

Lesion of cerebral cortex made by use of high tension sparks.

1 Spot on normal cortex just in front of the lesion and where excitation proved that the cortex in question was functionally active. (Cat.)

(B) The Lesion as Produced by Constant Currents.

Electrolysis by a constant current is, of course, a familiar subject, but little has been written on the immediate question, namely, the destruction of brain or central nerve tissue by its means, and when we were endeavouring to estimate its qualitative and quantitative effects we found that practically no description of the products obtained from cerebral tissue by the action of each pole existed. We have had therefore to spend a very considerable time in clearing up several points, not only chemical but also mechanical, which attracted our attention early in the research as well as attempting, with the kind assistance of Dr. Gordon

Lane, to form an opinion as to the basis of the chemical changes. We may therefore group the effects under the headings of: (1) *Mechanical;* (2) *Chemical.*

(1) *Mechanical effects.*—(*a*) *Transference.*—The knowledge of the migration of ions prepares one for the acceptance of the fact that in a compound tissue like that of the brain the lesions show a separation and localization of the chemical constituents of the tissues electrolyzed.

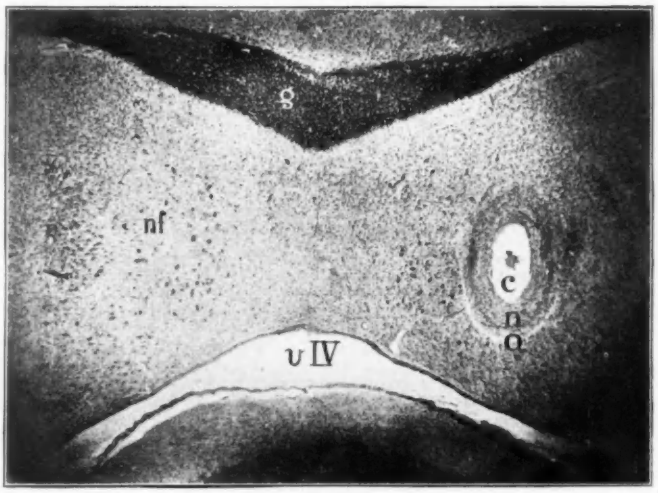

FIG. 15.

Anodal lesion made in the nucleus fastigii (outer group of cells) just before death. (Methylene blue.)

c Cavity of lesion.
n Necrotic zone.
o Œdema zone.
g Granule layer of a pyramid folium.
nf Nucleus fastigii. (Note [with lens] that the nerve corpuscles near the lesion stain more deeply and appear somewhat smaller than the normal cells on the opposite side, and that the layers of necrosed tissue exhibit concentric distension.)
vIV Fourth ventricle. (Dog.)

It is obvious that since as it has been shown that the conductivity of serum hardly differs from a 0·7 per cent. solution of NaCl, and that the rapidity of ionization in a gelatinous solution varies with the concentration of the latter (Leduc [8]), so the dissociation of the

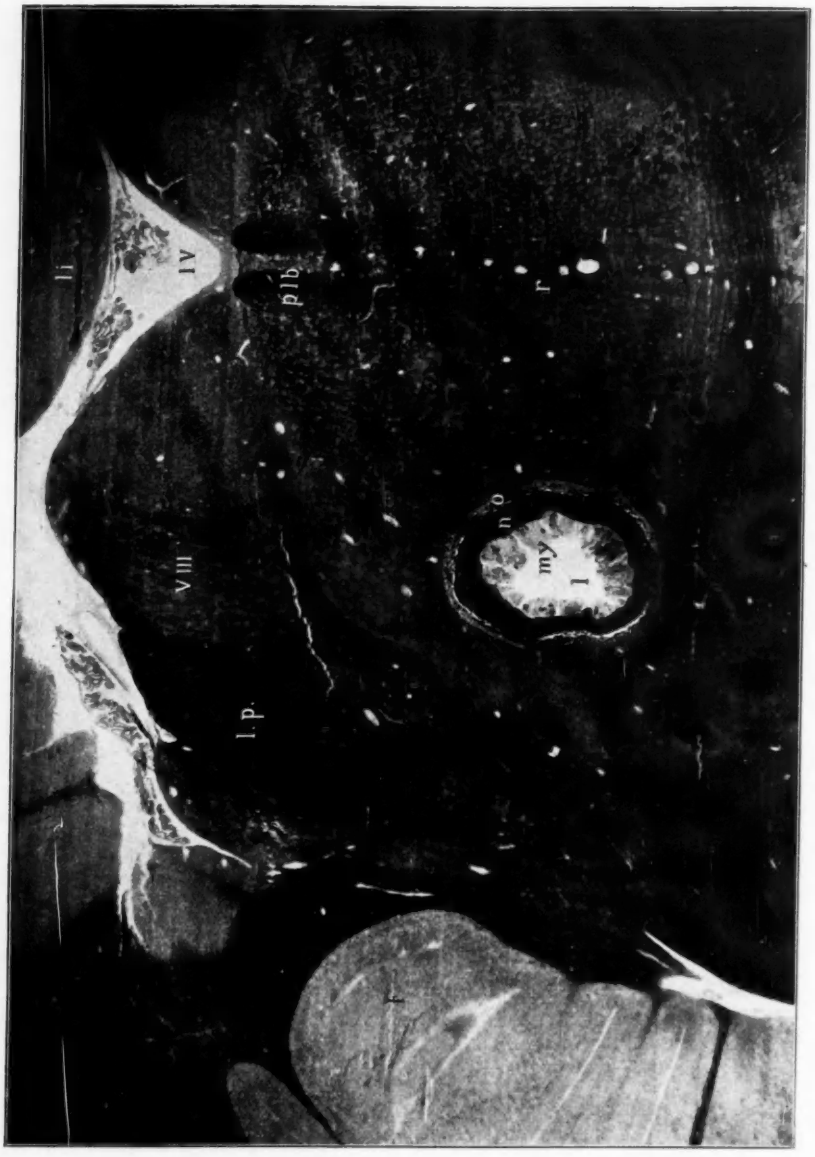

FIG. 16.

Anodal lesion, twenty-two days old, in the lateral region of the bulb. (Osmic acid.)

IV Fourth ventricle.
VIII Descending vestibular tract.
l Lesion cavity.
li Lingula.
l.p. Inferior peduncle.
plb Posterior longitudinal bundle.
r Raphe.
my Columns of myelin. (Note their radial arrangement.)
n Necrotic zone.
o Œdema zone.

cerebrospinal fluid of the blood and serum and of the neuroglia and nerve elements will proportionately differ and result in separation.

Our knowledge of this interesting phenomenon of convection, first demonstrated by Hittorf in respect of the greater velocity of the anion compared to that of the kathion, has been extended by Kohlrausch, who showed that if the kathion of different molecules remained the same the velocity would further vary according to the anion.

Finally, all investigators have shown that large complex molecules are more retarded than smaller ones.

From all these considerations it followed that a definite, if coarse, separation of the constituents of the nerve tissues might be looked for. Such is the case, and the centre of the lesions (*see* figs. 15 and 16) shows the complex fat-protein molecules as though left behind during the extension of the electrolytic processes; intermediately are the collagenous tissues, and furthest of all is a watery zone.

(*b*) *Distension.*—But in addition to this chemico-physical disarrangement by convection there is another mechanical effect which in our opinion is as powerful, and that is the distension or compressing effect of the gases developed in the lesion. These are present both in the anodal and kathodal lesions, but as for the same strength of current there is a greater volume of gas at the kathode than the anode, the mechanical destruction effected by the kathode is greater (in the proportion of 4 or 5 to 3) than that produced by the anode. In each case, however, there is an obvious disruption by the current of the tissues attacked and in each the pressure of the gas produces a condensation of the tissues as they are necrosed, this condensation resulting in the tissues being compressed concentrically with the axis of the lesion. This is exceedingly well shown in figs. 15 and 16, which represent respectively the condition of a lesion made (*a*) just before the death, and (*b*) three weeks before. When we first observed this mechanical distension effect of the gases and could not find that attention had been particularly directed to the point, we thought it was worth while to investigate the question a little further and to see how far destructive effects could be

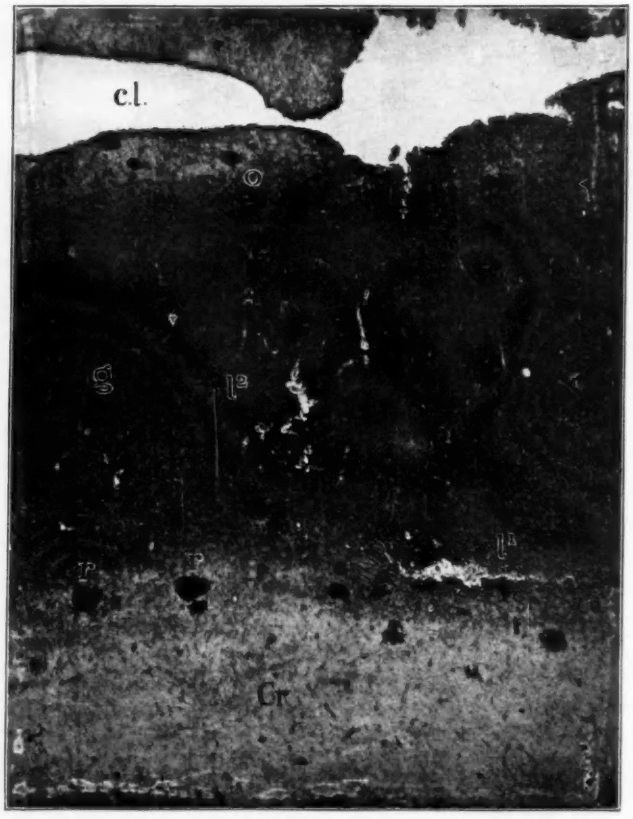

FIG. 17.

Experimental production of a lesion by injecting gas under pressure in water.

c.l. Central cavity of lesion.
o Œdema zone.
l^1 l^2 Lesions at a short distance produced by the gas and water following the perivascular lymphatics.
r r Thrombosed blood-vessels.
Cr Corona radiata.
g Section of the bottom of a sulcus, *i.e.*, grey cortex. (Dog.)

produced in living brain substance by gases under pressure and in solution. We therefore made sundry injection experiments, using hydrogen or carbonic acid gas and water under pressure. The result is shown in the accompanying photograph (fig. 17), from which it is evident that there

are considerable effects even at a distance from the source of pressure and further that the mischief spreads because the gas and water tend to force their way into and dilate destructively the perivascular lymphatics.

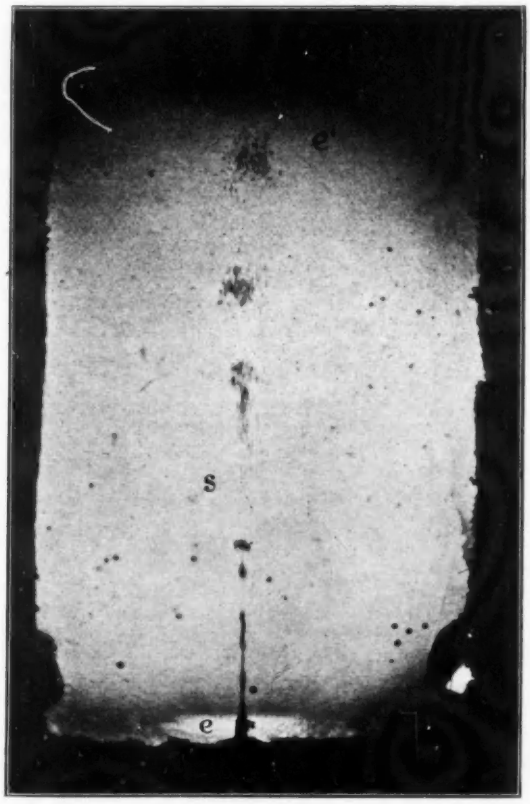

FIG. 18.

Instantaneous photograph of stream of gas, emanating from the point of the needle electrode, e, when it is a kathode. (The opposite electrode is just above, e'.) The solution, s, is transfusion saline fluid containing phenophthalmein. The colour developed by the reaction is shown as streaks left by the ascending bubbles

On this point, further, we have made comparative experiments with anode and kathode respectively to show, if possible, graphically a comparison between them when a moderate current (2 to 5 ma.)

is employed. For this purpose we fixed in a water cell, as shown in figs. 18 and 19, the positive and negative needle electrodes, and obtained, as seen in the instantaneous photograph, the proportionate amount of bubbles of gas developed by each. The character also of the evolution

FIG. 19.

Similar photograph, showing the much less quantity of gas developed and with less ebullition when the electrode, e, is an anode.

of the gas is seen to differ in the two cases, being more explosive and ebullitional from the kathode.

(2) *Chemical effects.*—The first and most striking contrast between anodal and kathodal lesions is the reaction, the kathodal lesion

being strongly marked by deep blue, whereas the anodal lesion in the brain tissue simply bleaches litmus; but as Dr. Lane has shown with di-methylamido-azo-benzol there is outside the bleached point a ring of acid reaction.

The anodal lesion.—The histological changes in the anode are so characteristic and useful for our purpose that we endeavoured to ascertain what chemical effect was produced there. The anodal bleaching effect is due to the chlorine dissociated from the NaCl, and the particular form of anodal coagulation of proteins and tissues is attributed by Leduc and others to the combination of the chlorine with the water and formation of HCl. Dr. Gordon Lane, however, was unable to estimate in anodal lesions of the brain the exact quantity of the acid, though in a solution of saline electrolytes resembling the inorganic constituents of serum, he was able to make the estimation accurately.

The kathodal lesion.—The chemical condition of the kathodal lesion as estimated by Dr. Lane is that a definite amount of alkali is developed, but when we compared the degree of tissue destruction in the lesion with the trivial effect produced in a normal living brain by the injection at any given point of a similar amount of alkali it was obvious that the latter, whether nascent or not, could not be a practical factor in the production, of the destructive effects.

(3) *Quantitative relations.*—On the question of the quantity of electrolytic destruction varying directly with the quantity of electricity employed, Dr. Gordon Lane has kindly made for us a very large number of titration experiments with electrolytic solutions resembling serum, the details of which will be published in full by him in this Journal.

The solution in the first set of observations was of two different degrees of quantity of electrolytes. Nevertheless, the same current, namely, 1 ma. for ten minutes duration, with a 23 gauge electrode, gave 0·00248 increase of alkalinity in the one, and the same current, time and electrode gave from the other solution 0·0026642, practically identical figures.

The next set of observations had relation to the duration of the application of the electrical current. In these the solution was electrolyzed for five, ten and twenty minutes, and the gain of alkalinity was respectively 0·0136, 0·00264, 0·00588.

It is evident that the relationship of time and quantity cannot be closer.

In Dr. Lane's third series of observations he compared different sizes

and different lengths of the electrolytic needle; it was found that results practically true to the fourth figure were obtained, and showed that for constant current strength and duration the resultant gain in alkalinity was the same whether the electrode needle was fine or coarse, short or long.

A fourth table of great quantitative interest was the proportionate gain in alkalinity evoked by different milliamperage. The average obtained was as follows: 1 ma. gave 0·0012, 2 ma. gave 0·00248, 4 ma. gave 0·00488.

The last point of more special interest is the relative action of the kathode and anode. We have repeatedly drawn attention to the anatomical changes produced by the gas pressures, but these do not fully indicate that the volume of the gas liberated at the kathode exceeds so largely that derived from the anode. Thus, in one of Dr. Lane's observations, a measured volume of gas was evolved by the kathode in twenty-four and a half minutes, but by the anode in only 108; hence in this experiment more than four times the volume of gas was liberated at the kathode.

To sum up, the determination of the electrolytic products in a simple solution of electrolytes is a certain and accurate process, because the relationship between quantity of current and effect produced is also very definite.

For full discussion, however, of the points involved reference must be made to Dr. Lane's full paper.

The Size and Nature of the Lesion.

(*a*) *Size and outline of the electrodes.*—The size and shape of the lesion depends in the first place upon the size, outline and position of the electrodes.

Unipolar needle.—The most restricted globular lesions we have obtained by employing a unipolar needle with but 0·5 to 1 mm. of platinum exposed, the other "indifferent" electrode being formed by all the points of contact of the instrument (*e.g.*, the frame fixing screws, aural pivots, &c.) with the head, or by insertion in the wound, or by a large indifferent plate electrode applied to the body.

With such an arrangement and an extremely fine wire as the unipolar needle it is easy to obtain destruction limited to very small groups of cells or bundles of nerve fibres. On this question of limiting the unipolar lesion it is important to note that when the other electrode has

been formed by the "live stop" or other termination in the wound it has appeared as though there was a certain extension of the electrolytic change along the track of the needle, the path of least resistance for the current, exactly as noticed in excitation experiments.

This also is demonstrated by the average shape of the lesion, especially when maximal currents are used and for a considerable time. Under such conditions the proportionate diameter of the lesion in the line of the axis of the needle to that at right angles is nearly as 2 to 1.

Bipolar needles.—Of the two forms of bipolar needles shown in fig. 12 that which we have called the concentric pattern produces a lesion the outline of which is a repetition of the form of the whole of the end of the electrode even when only the collar portion is employed, *e.g.*, as a unipolar anode. Similarly the other form of bipolar needle produces a lanceolate or flame-shaped lesion. It is thus quite clear that, as might be supposed, the area of nerve tissue which is damaged by the pressure of the point of the needle yields first to the necrosing effect of the current, and thus the shape of the electrode is of considerable importance for precise topographical limitation of the lesion.

(*b*) *Quantitative production of the lesion.*—In the second place the size of the lesion depends on the amount of the current employed. We originally hoped that we should be able to regulate the degree of destruction entirely in accordance with Faraday's law, and that the quantity of decomposition of the tissue would be directly proportional to the quantity of electricity employed (Arrhenius). In this we have only been partly successful, the reason being that the factor of time carrying with it also the alteration of resistance deprives the method of mathematical accuracy. We have, however, by accumulating a large number of experiments, been able to arrive at a clear understanding as to what is necessary to produce a given effect. On this point the diminution of resistance to which allusion has just been made must first be referred to. The readiness of living tissues to polarize has long been recognized, and the fall of resistance, which has been a striking and constant phenomenon in our experiments, is proportional to the ionization and coagulation obtained. It can be readily compensated, and by a sliding resistance we have thus kept the experimental condition constant as far as possible during the process of making the lesion. The quantity of electricity we have used (*i.e.*, milliamperage and duration of application), and especially in its first factor, which has varied during the last two years only between 1 and 5 ma., is much smaller than that employed by our predecessors, hence we cannot enjoy the advantage of comparison with their results.

Moreover the wide difference of effect according to the contrast in polar action such as we are about to describe has not been employed by other experimenters; this has influenced us so much in favour of the anode that any comparison between the size of the lesion and the quantity of electricity required to produce it ought in future to be considered as referring to an electrode used as an anode.

High milliamperage is wholly unnecessary; thus 1 ma. produces an adequate effect in a few seconds (fifteen) on a single group of cells, but 2 ma. give a more constant result, and a hyper-maximal effect is reached with 5 ma.

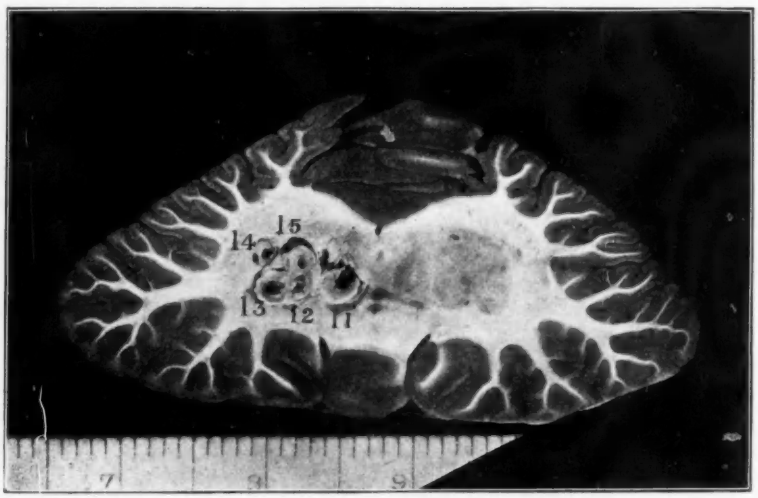

FIG. 20A.

Five anodal lesions, 11—15, made three weeks before death to destroy the nucleus dentatus, embolus, globosus and outer part of nucleus fastigii. (Note that the lesions have been made by successive insertions of the needle, and that the object of the procedure is attained with minimal injury to surrounding parts. The smaller scale divisions are millimetres.) (Macacus rhesus.)

Next, as regards the influence of time, which must be considered directly with that of milliamperage, our experience has been that although a notable effect is produced within a few seconds, the amount of further destruction proportionately diminishes as the time is prolonged. We have not, however, worked out any definite curve of this diminution, but in a number of preliminary observations we found

FIG. 20.

Margin of a large kathodal lesion made just before death.

ca Central cavity of lesion. Below the letters is a large mass of necrosed tissue and clot. To the left is the advancing necrotic border, n, showing numerous gas bubbles, bu, and largely consisting of altered, *i.e.*, electrolyzed, blood-corpuscles.
o Œdema zone.
g Normal gyrus.
s Normal sulcus.

that it was so marked[1] as to render any increase of the time above five minutes purposeless. For practical purposes a rough average of quantities and proportional effects may be drawn up as follows :—

Kind of lesion.	Size of lesion.	Quantity of current.	Duration of electrolysis.
Simple anodal lesion ...	2·7 mm. ...	3 ma. ...	1·8 min.

Combining many observations together it is evident that for a unit of time, *e.g.*, one minute, there will result about 1 mm. breadth of destruction for each 1 ma. of current employed. This, of course, is only approximate, and only true within about 5 ma.

We will next describe the structural changes wrought in the cerebral and cerebellar tissues by the electrolytic processes.

Macroscopical Anatomy of the Lesion.

From what has been already stated it will be realized that, whether anodal or kathodal, the lesion presents three zones on naked-eye examination, *i.e.*, a central cavity (containing gas, watery fluid, myelin, &c.), a zone more or less broad of necrosis, and outside that a narrow zone of œdema. All these three zones are extremely obvious within a month after the lesion is made, but we have not yet examined the ultimate fate of the lesion after longer survival periods. To the naked eye the differences between the polar effects are very obvious and coincide with the descriptions given of and results obtained by electrolysis of the blood. Thus the anode produces a small central cavity surrounded by a compact greyish pink coagulation or necrotic area ; the kathode causes, on the contrary, the production of a larger cavity filled with a rosy pink fluid, often almost gelatinous in its viscosity, the walls of the cavity showing the presence of bubbles of gas and consisting of necrosed tissue, which is whitish yellow, soft and diffuse. These differences are shown in the accompanying photographs, figs. 20, &c.

Similarly the œdema border around the kathodal lesion is proportionately wider than that bordering the anodal injury.

Microscopical Anatomy of the Lesion.

The microscopical details of the changes produced are of the highest importance, and especially because they show at once the great

[1] As an example we may quote the figures obtained from an experiment on this point, as follows : Needle, 22 gauge ; amount exposed from glass sheath, 2·5 mm. ; place, dentate nucleus ; pole, kathode ; amount of current, 5 ma. ; duration, thirty minutes ; result, lesion 8 mm. in line of needle ; 6 mm. at right angles to same.

advantage of this method of making experimental lesions, namely, that the injury produced is sharply delimited from the surrounding tissues, and consequently the loss of physiological function is strictly confined to the seat of electrolysis. As a side fact, a physiological proof of this may conveniently here be stated. It is that when, during an excitation

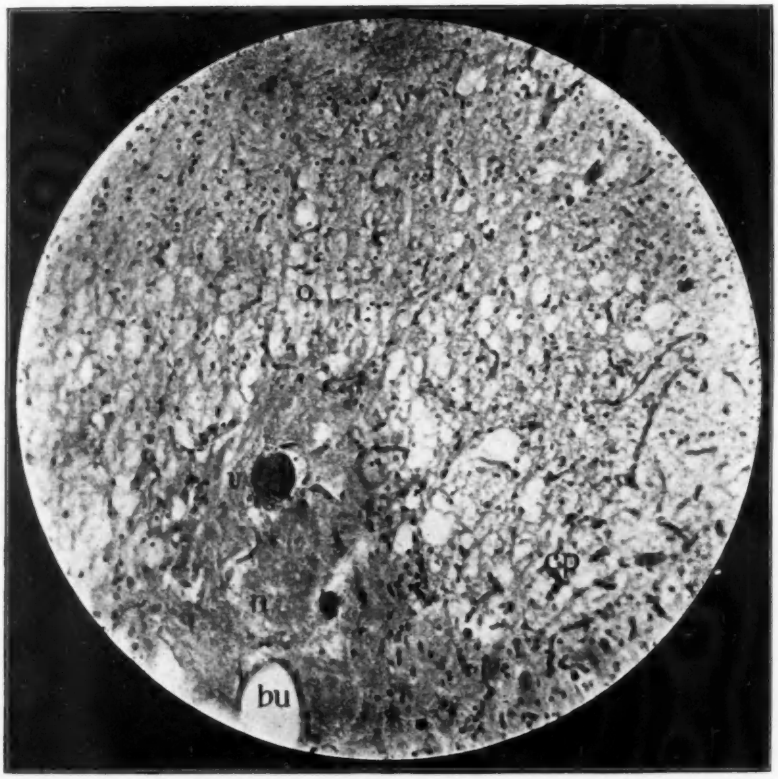

FIG. 21.

Section of margin of kathodal lesion made just before death, showing the dissociation of the neuroglia by the gas and fluid forming the œdema zone, o; the edge of the necrosed tissue, n; a gas bubble, bu; congested capillaries within which thrombosis has occurred in some, cp.

experiment, a restricted electrolytic lesion has been made to mark some spot from which a definite response has been obtained, we have found, on advancing the needle another millimetre, that the uninjured tissue immediately adjoining is normally excitable.

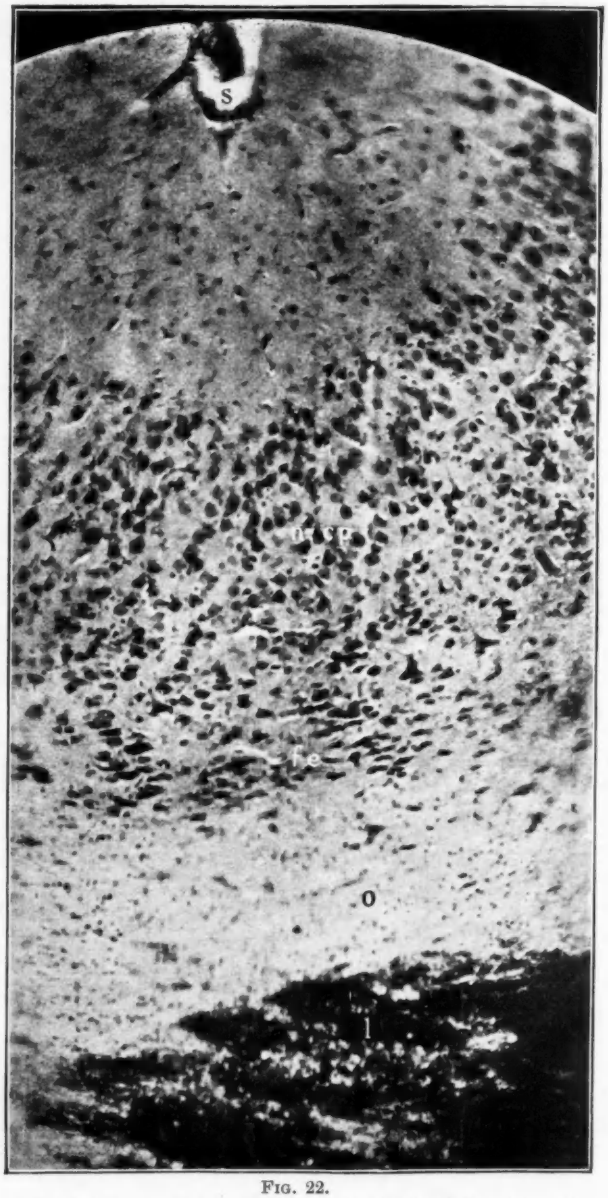

FIG. 22.

Vertical section of gyrus and kathodal lesion just below it, l, made just before death. The lesion shows laked blood and numerous very small gas bubbles. The œdema border, o, extends to the cortical layers of cells, of which the lower layers, fe, are flattened by the gas pressure, whereas the upper layers, n. cp, are normal; s = bottom of a sulcus. (Cat.)

FIG. 23.

Margin of an anodal lesion made just before death in the bulb close to the motor nucleus of the fifth cranial nerve, no, showing the compression and destruction effects of the electrolytic lesion on a portion of a nucleus. The neuroglia, partly in solution, is shown at the bottom left hand corner at l. The nerve cells involved are seen flattened and distorted at fl, whereas the cells in the rest of the nucleus, n o, are still functionally active.

To proceed now to the details of the microscopical changes observed, we can most conveniently condense the large amount of material we have collected by grouping the facts under two heads: (1) lesions created just before systemic death; (2) lesions created three weeks before death.

The second class naturally only presents as additional features the phagocytic processes of removal of the necrotic tissues and products, as well as certain stages of commencing repair.

(1) *The Histology of the Electrolytic Lesion when Made just before Death.*

Although the first and principal change in the entire living brain is the electrolysis of the blood and lymph, the nerve tissues begin to break down very soon, and the fate of the different components may be taken separately.

(*a*) *Changes in the neuroglia.*—The changes in the neuroglia must be considered according to the degree of destruction.

(1) *Zone of necrosis.*—The nuclei of the neuroglial cells rapidly lose their capacity for staining with basic dyes, though the nuclei of leucocytes still stain readily.

Similarly the neuroglia fibrils refuse to stain, and in differentiating polychrome methylene blue stained sections the compressed nerve tissue (which subsequently necroses) decolorizes before the normal from which it is sharply marked off.

Before disappearing the nuclei become distorted and shrunken, though for a long time their outlines or nucleolar contents can be recognized in the necrotic coagulum. The fibrils and "punkt-substanz" of Retzius become fused into an amorphous mass, which under a high power looks like a coagulated precipitate, but is notably denser than the precipitate in the cavity of the lesion, which is certainly altered blood-plasma and has a loose floccular and granular appearance.

(2) *Zone of œdema.*—In the zone of œdema which immediately surrounds the necrotic core and separates it from the normal surrounding tissue the meshes of the neuroglia are simply torn open, thus forming spaces. The stages by which this is produced are seen in the photograph, fig. 21, where the small holes showing themselves in the section bear a relation to the cell spaces of the tissue generally, and, moreover, are exactly similar to the small cavities produced by the injection of hydrogen into the cerebral tissue.

The nuclei of cells of the all connective tissue type become granular,

the protoplasm of the body of the cell ceases to stain, the nuclei begin to shrink, and as they shrink often take the dye excessively and appear almost as black points.

A coagulation precipitate (exceedingly fine) can be seen between the fibres forming the œdematous border of the tissue which is necrosing and which will form the zone of necrotic tissue.

(*b*) *Changes in nerve cells.*—The earliest change is a general fusion tigrolysis. The cell bodies stain darkly, ultimately intensely darkly, and then proceed to shrink, the contraction naturally being most marked at first between the dendrites.

This general change applies to all nerve cells.

The details of the change merit further investigation. As far as we have seen the tigroid bodies first contract and the intervening cell substance tends to stain diffusely.

With the shrinking of the tigroid body (which renders it very narrow in longitudinal section of the cell and point-like in transverse section) there is also intenser coloration of it.

While this alteration is proceeding in the body of the cell the axone and dendrites are undergoing a disappearance of fibrillar structure followed by swelling and paling, and this again by shrinkage and deformation.

The cells thus degenerating in the zone of necrotic compression also show very interesting mechanical defects by torsion, especially in the large dendrites and axone (*see* fig. 23).

Further, by reason of the contraction of the tigroid bodies, spaces like vacuoles appear in the protoplasm of the cell, and often are strictly circular in outline as though holding fluid. In many instances the remaining chromophile substance is aggregated at the border of the cells, in others more rarely round the nucleus.

The nucleus does not move towards the side of the cell, but as it shrinks it becomes more deeply stained and shrivelled on the nucleolus until it stands out in sections as an intensely dark point.

(*c*) *Changes in nerve fibres.*—Nerve fibres attacked by the electrolytic process are apparently simply dissolved. In accordance with the like changes in the connective tissue protoplasm the axis cylinders within the neurotic zone refuse to stain with polychrome methylene blue, but they can readily be distinguished and particularly as they do not swell before disintegration.

The myelin of their sheaths flows in the liquid in the lesion cavity as the fibres undergo dissolution. Indeed, in some preparations (*see*

fig. 16, 25) it appears as though the compression of the necrotic zone by the gases in the cavity caused the myelin to ooze out and be left in trails radiating from the centre of the lesion, *i.e.*, arranged in columnar fashion as though along lines of electrolytic convection.

The fate of the myelin will be discussed later, but attention should here be drawn to the fact that as it escaped from the fibre sheaths it is but little altered and consequently it gives to osmic acid practically the same reaction stain as a normal fibre.

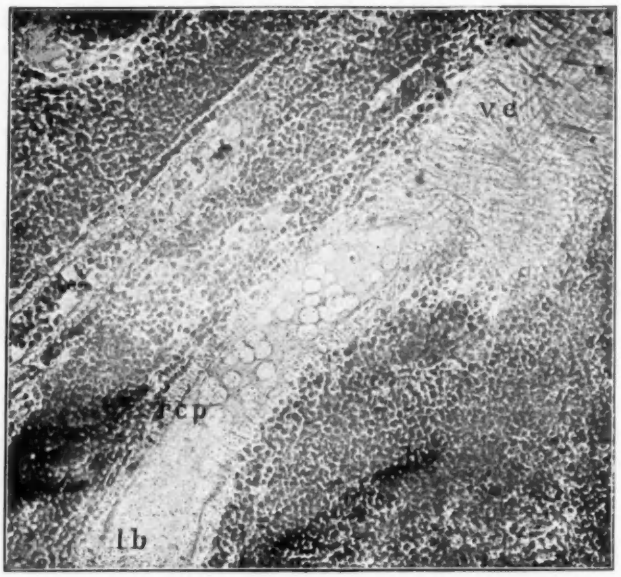

FIG. 24.

Electrolytic changes in a vein and blood. Kathodal lesion.

v e Vein wall undergoing dissolution.
r c p Stromata of red corpuscles swollen and lying in blood, which is completely laked at l b. Surrounding the vessel are shrunken blood-corpuscles, h g, lying in the cavity of the lesion.

In summary it may be said that the alteration of the nerve fibres indicates the destruction to consist of a progressive solution, so that there is practically little interval between the disappearance of the structure and the complete fibre.

(*d*) *Changes in the blood-vessels.*—The altered condition of the blood-vessels first evinces itself in the immediate neighbourhood of the lesion

by thrombosis of the smallest vessels. The blood slightly coagulated shows no change in the corpuscles.

Later, the muscle fibres in the wall of the vessel undergo a cloudy swelling metamorphosis and then show considerable hyaline changes. A vessel in this condition is often seen hanging in the lesion cavity and undergoing at its free end a solution of its elements. Such a vessel while intact contains a thrombus consisting of altered corpuscles, but as the next result of the electrolytic process is a liquefaction, such thrombi are very fragile and partial.

The dissolution of the elements of the vessel wall is not without interest, as the most resistant are the endothelial layer and elastic lamina, and further because there is a very short stretch between the point of complete destruction and that of a fairly complete vessel.

(*e*) *Changes in the blood.*—The changes in the blood commence with the dissociation of the red corpuscle in the manner indicated by Brücke forty years ago. The pigment holding protein compound (Brücke's zooid) escapes from the stroma and consequently aggregations in the neighbourhood of the lesion of partly decolorized stromata within the vessels are a characteristic feature of the electrolytic process. Such stromata stain a greenish purple with polychrome methylene blue.

This results in an early laking of the blood, and the decolorized stromata soon become invisible in the highly tinted plasma. Nuclear stained sections often show the vessels containing thoroughly laked blood in which are floating practically unaltered leucocytes (*see* fig. 24).

The next stage affords a highly interesting instance of convection, for the colouring matter (protein compound) is carried through the wall of the vessel and collects in nodular masses, leaving the contents of the blood-vessel evidently little more than water, as there is frequently no protein precipitate in it.

The blood in large vessels passing through the lesion affords interesting points for study of the corpuscles apart from the convection phenomenon above mentioned. The red corpuscles become crenate and irregularly shrunken, showing bright particles of hæmoglobin without arriving at the later stage of hæmosiderin, but granules of the last-named substance are seen in quantity in the *débris* in the lesion.

(2) *The Histology of the Electrolytic Lesion Three Weeks After.*

The chief differences between the lesion immediately examined and that in which the animal has been kept alive three weeks before death are essentially summed up in the word phagocytosis, for all the conditions

as just described are present, namely, the necrotic zone, its central cavity and the zone of œdema. We will therefore begin with the phagocytic cells (*see* fig. 25).

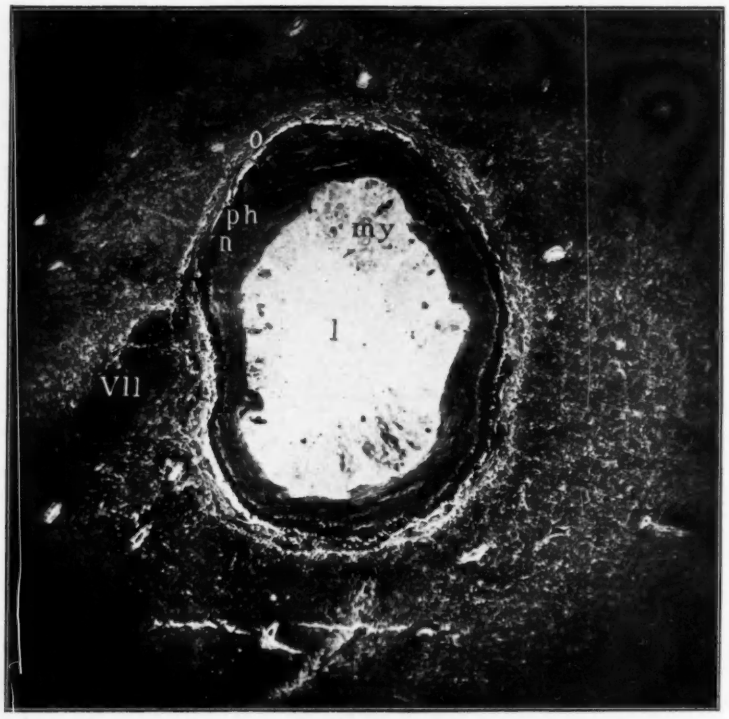

FIG. 25.

The lesion, made three weeks before death, in fig. 16, *more highly magnified.*

l Cavity of lesion, containing a few leucocytes and much myelin in radiating columns, my. The necrosed tissue, examined with a lens, shows well the distension effect of the gas content of the lesion. The dense black ring of phagocytes, ph, closely surrounds the necrosed tissue and the two other subzones of the œdema zone, o, are well marked.

VII The seventh cranial nerve totally degenerated, being divided by the lesion.

(1) *Distribution of phagocytes.*—A very interesting characteristic is noticed where a restricted globular lesion has been made deep in the substance of the organ and where consequently the wall of necrosis is unbroken. It is then seen that though the phagocytes are thickly aggregated in the œdema zone they nowhere succeed (within twenty-five days) in

FIG. 26.

Section (methylene blue) showing the margin of a kathodal lesion made four days before death.

ph.s, indicating the genesis of a large phagocyte, is placed on the normal neuroglia at the extreme border of the œdema zone.

O is placed in the middle subzone in a (watery) space.

S.ph marks the line of phagocytes, the innermost subzone.

pl is a large phagocyte abutting on the necrotic tissue which lower down is marked n. (Dog.)

penetrating the necrosed tissue or coagulum or gaining the cavity of the lesion. The few stray cells occasionally met with on the inner side of the wall are obviously surviving leucocytes. On the disputed question of the genesis of Gluge's corpuscles it is interesting to note that these scattered

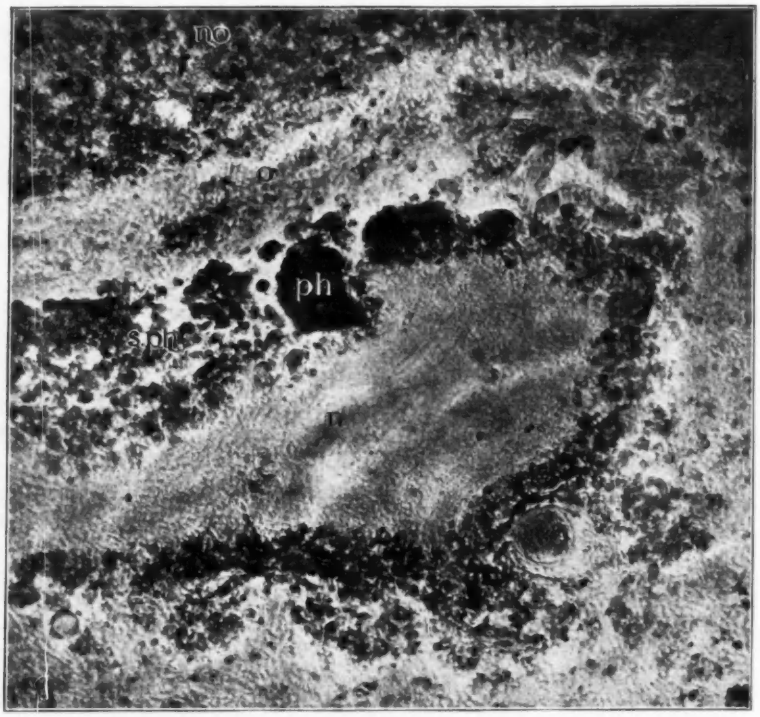

FIG. 27.

Margin of an anodal lesion twenty-two days old, showing the subzones of the œdema zone and the two classes of phagocytes.

n Necrotic tissue.
S.ph Innermost subzone, containing many small phagocytes.
o Middle œdema subzone.
ph Giant phagocytes
n o Outermost œdema subzone, showing now only infiltration, with small granules stained black by osmic acid. All the phagocytes are full of such granules. (Macacus rhesus.)

cells only take up a few particles of blood-pigment or very little myelin. They are not comparable, therefore, with the ordinary phagocyte or Gluge's corpuscle. Consequently the distribution of the phagocytic cells

(the true Gluge's corpuscles) in the œdema zone is extremely easy to map out.

For this purpose the œdema zone may be divided into three concentric zones: an innermost, a middle and an outer subzone (*see* figs. 25 and 26).

(*a*) The innermost subzone consists of a layer of phagocytes arranged column-wise in three or four concentric rows, but closely packed together and full of fine granules staining intensely black with osmic acid.

(*b*) The middle subzone is a watery layer in which float phagocytes and neuroglial *débris*, half destroyed vessels, blood partly clotted in various stages of absorption, myelin droplets, &c.

(*c*) The outer subzone contains very few phagocytes, but consists of the slightly affected edge of the normal tissue, that part of the œdema zone in which from the first a fine precipitate can be seen in the meshes of the neuroglia.

(2) *The character of the phagocytes.*—The shape, arrangement and contents of the cells differ in the three subzones, and may best be described *seriatim*.

(*a*) *Innermost subzone.*—The phagocytes which attack the outer surface of the necrotic coagulum resemble plasma cells in every particular. As a rule they are small, narrow and club-shaped, owing to their radial and packed arrangement in the œdema zone. At points in this ring of phagocytes giant-cells appear and many intermediate shapes, but the large protoplasmic masses, though staining a very dark brown, rarely contain more than a few granules (*see* fig. 27). The smaller the cell as a rule the more completely is it filled with myelin granules, obscuring the nucleus. In some the granules fuse into two or three large vacuoles filled with feebly staining myelin.

(*b*) *The middle subzone.*—In this layer, which is the true (separation) line of the necrosed tissue, we find large spaces filled with clear fluid or altered blood; the phagocytes floating freely are, as a rule, spherical in outline (*see* fig. 28). These are comparable to those found in extensive ischæmic softenings in man (*see* fig. 29).

(*c*) *The outer subzone.*—Running outwards from the edge of the œdema cavity are degenerated fibres which arose from the nerve cells destroyed by the lesion or are the peripheral portions of those which have been severed. The neuroglia between them is no longer water infiltrated, but there is a fine granular precipitate, which stains brown with bichromate of potash and osmic acid, as well as numerous fine black granules.

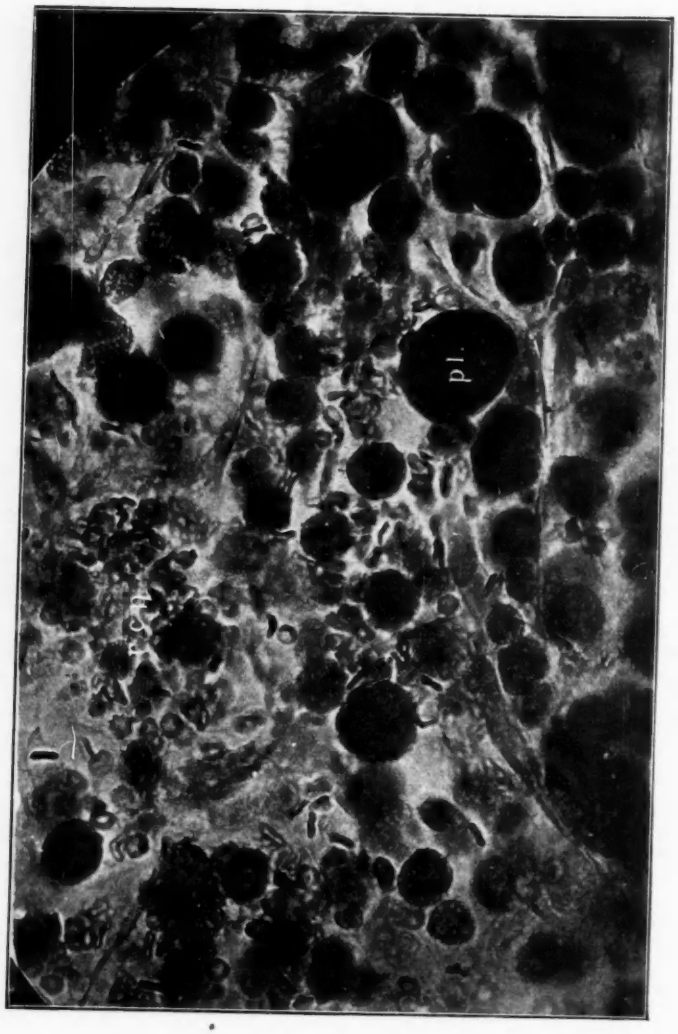

FIG. 28.

Phagocytes in an anodal lesion on the border of the fourth ventricle.

All the phagocytes contain many granules, which stain deeply with osmic acid. The large cells, p l, do not take up the red blood-discs, however altered. Of the red corpuscles, r c p, many still preserve a normal outline. (Macacus rhesus.)

V.—The Method of Excitation.

The systematic investigation of the functions of the cerebellum by the excitation method has been attempted by relatively few observers and only of the cortex cerebelli. The first was Ferrier [1], who employed the faradic current, and explored the cerebellum in different

Fig. 29.

Phagocytes (Gluge's corpuscles) large and medium size, from a cerebral ischæmic lesion, to compare with fig. 26. (Man.)

classes of animals. He was followed by Hitzig, Nothnagel and Dupuy, the first of these using the constant current, the latter mechanical irritation, which had already been attempted by Leven and Olivier and Weir-Mitchell. In later years, Sherrington, Löwenthal and Horsley, and

Rijnberk, Lewandowsky, Pruss and Lourié have contributed short communications on the subject.

We will refer to the results obtained by those observers later in our second paper and here only discuss the following points of practica interest, which appear to us to govern the whole subject, and which certainly afford a test of the value of any particular method of investigation. These are :—

(1) Excitability of the cortex cerebelli.

(2) Relative excitability of the cortex cerebelli compared to that of the cortex cerebri.

(3) Relative excitability of the cortex cerebelli compared to that of the nuclei cerebelli and efferent tracts therefrom.

With the means described in this paper the functions of all these parts can now be adequately examined and differentiated, provided that some general principles are fulfilled.

(1) *Excitability of the Cortex Cerebelli.*

We begin by raising a fundamental question, viz., whether the cortex cerebelli is strictly speaking excitable to electrical stimuli. Ferrier records that in his experiments, using the interrupted current as stimulus, he obtained positive results in but a relatively small proportion of experiments, and to those who, like Nothnagel (*cf.* Pagano), employed a mechanical stimulus, viz., a needle point (sometimes heated), negative results were extremely common.

The explanation commonly given of these facts is that the difficulty of the operative procedure for exposing the cerebellum causes shock effects to the delicate cortex from loss of blood, &c., and so lowers its excitability.

We may most conveniently dismiss now this question of hæmorrhage and what is, in our opinion, the equally important matter of cooling. Though these adverse conditions have evidently occurred very frequently in previous researches on the cerebellum, they can be completely avoided by suitable care in operation, *e.g.*, by careful study of the situation and grouping of the blood-vessels, the use of lenses,[1] reflected illumination, constant irrigation with warm saline solution, large hot water trough support, &c., and finally by the instruments and topographical methods already described.

[1] For exact adjustment of the apparatus used we have found magnifiers, as very kindly arranged for us by Mr. Henderson (viz., Sp. +7 combined with prisms +6 and fixed in a strong spectacle frame carrying mesially a concave mirror), quite essential. All the blood-vessels are strikingly revealed by such glasses and the topographical identification of any spot which has been determined by measurement is rendered easy.

Given all the operative conditions just stated, the negative results obtained by previous observers are, in our opinion, the genuine expression of what we have found to be characteristic, namely, that the cortex cerebelli is relatively inexcitable. This, of course, raises a new issue regarding the cerebellum, and we will now proceed to discuss the evidence in our possession. The first factor to be considered is the kind of stimulus employed. We will take the various methods and procedures which have been tried and begin with the less exact.

(*a*) *Mechanical stimulus.*—The cortex cerebelli itself has not been carefully examined with mechanical excitation, but Leven and Olivier, Weir-Mitchell, Hitzig, Nothnagel, and Dupuy have stated that mechanical puncture of the cerebellum sometimes causes movements which other methods suggest may be represented in the organ, but whether in the cortex or nuclei was not in the minds of these authors. Dupuy observed in addition to movements definite indications of algesia.

On this last point our observations are not strictly parallel, as they have all been made on anæsthetized animals, but as regards the question of mechanical excitation during the insertion of the insulated needle we have noted very exceptionally distinct motor effects which we believe are due to excitation of the subjacent nuclei or efferent paths from them. But though an effect may be observed to follow a puncture or slight stab of the cerebellum, that does not afford any proof that the cortex cerebelli as such has been excited, since every puncture of necessity involves the subjacent fibres, and in many cases the nuclei also.

The immediate effects observed by Pagano with injections of curare are similarly explicable and do not, we think, admit of interpretation as restricted and localized stimuli. Indeed, Pagano recognizes that the cortex cerebelli is very resistant to excitation, and that the general effects produced by his method are of diffuse origin is proved in his demonstration that excision of the opposite excito-motor cerebral cortex abolished the results.

(*b*) *Constant current stimulus.*—Hitzig found that the cerebellum (*i.e.*, as a whole) was definitely excitable to the constant current, but he naturally at that period did not discuss the present question of how far the motor response is ascribable to the cortex. In accepting his facts we cannot but deduce from our own experiments that there is a very sharp contrast between the reactions of the cerebrum and cerebellum to a galvanic and faradic stimulus respectively. The "shock" character of the galvanic excitation ("make" and "break") renders this mode of stimulation applied to the central nervous system much less precise than the faradic current in differentiation of reaction.

In fact, Hitzig's interesting observation that when by stimulating the "upper lobes" skew deviation of the eyes resulted, the direction of such deviation was reversed with the reversal of the current, seems to us to show that the excitation effect was not limited to the spot of application of the cortical electrode. Our own observations lead us to believe that as a stimulus the constant current cannot be ranked for accuracy and limited localization with the induced current, and further, that no proof is yet to hand that the cortex cerebelli has been excited alone in any experiments so far published.

We have during the past three years accumulated a large number of facts on excitation with the constant current in comparison with the interrupted current, since by our method when we proceed to mark by electrolysis a spot which has just given a certain response to faradic stimulation we cause both an opening and closing effect on the same tract or nerve centre as the case may be.

The results have fully borne out the foregoing statement as to the disadvantages of the constant current excitation, and especially its diffuse and shock-like effect. We need not, therefore, dwell further on this point, but turn to another interesting phenomenon which we have also observed and which appears to us to be explained simply as another form or demonstration of the principles of complex representation of Hughlings Jackson and of reciprocal innervation of Sherrington.

It is that if a definite motor response, *e.g.*, flexion of the elbow of the same side, is evoked by faradic stimulation of the dentate nucleus the antithetical or reciprocal movement, *e.g.*, extension, will be the response to galvanic excitation.

An indication of the same phenomenon we have also occasionally seen while employing the same (*e.g.*, faradic) stimulus if the nuclei are fatigued, and when contractures have already set in.

This is a further instance of the special modification of a motor response, as one of us (V. H.) showed ten years ago, for spinal centres [5].

(*c*) *Interrupted current stimulus.*—We have followed Ferrier in employing the faradic current as the most reliable stimulus (furnished by a Kronecker coil with one or two Obach dry cells in the primary circuit), and we have used it both by bipolar and unipolar application.

Our final conclusion is that though the cerebellum, *i.e.*, cortex and nuclei, *as a whole* responds to the faradic stimulus the presumed excitability of the cortex cerebelli is extraordinarily low compared with that of the cortex cerebri and that, comparatively speaking, the former is

inexcitable. Further, that, as will be seen presently, the values obtained for different depths of insertion of the electrodes show not only that the cerebellar cortex is not directly excitable, but the cerebellar nuclei are, and to a high degree. The preliminary point of difference in the character of the effect according to the method of stimulus, *i.e.*, whether "unipolar"[1] or "bipolar," also requires very careful consideration. This is especially necessary since, although the unipolar[2] method offers at first sight special advantages in the exploration of deeply situated central mechanisms, it theoretically and actually conduces to errors of observation.

(*d*) *Bipolar excitation.*—When the bipolar method is employed with the electrodes 1 to 2 mm. apart the cortex cerebelli gives no response on the average until the 4,000 or even the 8,000 point on the Kronecker scale is reached. It was soon obvious to us in exploring by means of the unipolar method the posterior surface of the cerebellum, covered as it is by the strong arachnoid membrane forming the posterior and lower limit of the large cerebrospinal fluid *cisterna* opposite the lower third of the cerebellum and obex, that lateral escape of the stimulus to the margin of the fourth ventricle[3] and to the trunk of the spinal accessory nerve frequently occurs. Probably most previous descriptions of representation of trunk muscle movements in the cerebellar cortex based upon excitation experiments are to be accounted for by this accidental error.

This erroneous effect is composed primarily of movements of the upper shoulder group of muscles, so that its topography is obvious, while the character of the response is so sharp that it definitely displays itself as the effect of a peripheral nerve excitation rather than that of nerve centres such as in the cortex cerebelli.

We have made a series of experiments to compare in this respect of causing local error the unipolar and bipolar methods of excitation respectively. The results are not only striking as showing what very special care must be used in employing the "unipolar" method for localization experiments, but the subject is also of such vital importance to the present investigation that we devoted much time to investigating with the faradic current the whole question of the absolute and relative excitability of the cerebellar cortex.

[1] *Cf.* Sherrington [22].

[2] The expression unipolar frequently applied to faradic current is really scarcely accurate although perhaps convenient. We have therefore made special investigation of the use of one electrode, and the full discussion of the question is given subsequently. (*See* pp. 119-121.)

[3] *I.e.*, region of nucleus gracilis, nucleus cuneatus, the tubercle of Rolando, &c.

In the first place we established as standards the excitability of the frontal and occipital cortico-cerebral areas for the movement of conjugate deviation of the eyes, and as an example of the comparisons obtained here subjoin the results of a typical experiment, which shows the minimal stimulus required to evoke the movement of *conjugate deviation of the eyes*, from the different chief points in the encephalon in which that movement is represented.

	Cerebrum.				Cerebellum.	
	1	2	3	4	5	6
	Inferior frontal gyrus (Conjugate deviation of eyes centre.)	*Corona radiata cerebri beneath No. 1.*	*Occipital lobe, upper and outer surface.*	*Corona radiata cerebri beneath No. 3.*	*Left half of vermis pyramid.*	*Left nucleus fastigii region.*
Minimal stimulus in Kronecker coil-units of current	... 100	... 30	... 200	... 50	... No effect at 2,000	... 10

We next proceed to study the relative effects of unipolar and bipolar stimulation. To the bipolar method of faradic excitation, the electrode points being either 1 mm. or 2 mm. apart, we have found that the cortex cerebelli is unquestionably not excitable, *i.e.*, no muscle response followed the application of the electrodes even when the coil distance represented 4,000 units of the Kronecker scale, and in some cases even 8,000, *i.e.*, at a point when the tension of the current was sufficient to cause frequent sparking between the electrodes when separated 1 mm.

When the whole surface of the cerebellum was thus explored with a hypermaximal stimulus the trapezial group of muscles began to contract with gradually increasing force as the electrodes were gradually brought down towards the edge of the fourth ventricle, and lower still to the neighbourhood of the spinal accessory trunk.

The delimitation of the spinal nuclear representation of the trapezius and other cervico-scapular muscles has not to our knowledge been specifically determined.

We have therefore made a few observations on this point as follows:

(*a*) *Anatomy.*—The most oral root of the *spinal* accessory nerve takes superficial origin from the bulb in the:—

(1) Cat. In the zonular level of the angle of the posterior border of the external arcuate fibres.

(2) Dog. In the zonular level of the same point.

(3) Monkey (*Macacus rhesus*). In the zonular level of practically the same point, *i.e.*, about 1 mm. above the obex.

Thus the bulbo-spinal representation of the shoulder muscles must be regarded as extending headwards as far as the large celled vestibular nucleus and consequently all excitation of the posterior cervical roots, and of the columns and nuclei of the obex region, will theoretically respond by contraction of the muscles named.

(*b*) *Physiology.*—Risien Russell [18], by excitation of the anterior cervical roots, showed that the first cervical nerve supplied the trapezius with other muscles. We have obtained the same response on stimulation of the bulb: (1) Nucleus gracilis. (2) Nucleus cuneatus. (3) Tubercle of Rolando.

That these results are due both to direct excitation of the bulbar representation and escape to the accessory trunk itself is proved by the fact that excitation after section of the highest roots is followed by the trapezial group movement though weaker.

With unipolar excitation the errors due to escape of current appear much earlier than with the bipolar method, and we will now give further facts which show the misleading character of the response to unipolar excitation of the surface of the cerebellar cortex.

For unipolar excitation we employed as the localizing (or as Sherrington terms it the "stigmatic") electrode the glass-insulated needle before described, and for the other either the wide attachments of the brass head piece or a broad metal plate expansion, which was inserted beneath the skin of the back or applied to any other selected spot. We also tried as a diffusing electrode a large area of wet linen applied to the shaved surface of the skin of the lumbar region.

When the surface of the cerebellar cortex was explored with the single insulated needle point and one of the above-named "indifferent" electrodes, the first effect was observed when the Kronecker coil strength reached 1,600 units. The response that then followed was invariably contraction of the trapezius, usually of the same side, but with stronger currents, *e.g.*, 2,000, &c., it easily became bilateral.

The degree of this typical response always steadily increased as the exciting electrode point was brought down towards the nucleus cuneatus. The natural conclusion follows that the effect was an "escape" phenomenon, and therefore such unipolar responses cannot be accepted as evidence of function.

To test this further, and to get if possible some idea of the amount of

the error produced by the conditions of application of the electrodes, we next tried several variations of the unipolar excitation method. In the first place we found that the muscle response was notably diminished by

FIG. 30.

Normal cerebellum in the cat enlarged to show how the white fibres in the paramedian fissure (between Py and P) lie on the surface, and consequently exposed to any stimulus applied in the region of the sulcus.
df Dorsal parafloccculus.
Py Pyramidal lobe.
P Paramedian lobe.
The smaller divisions on the scale are millimetres.

shifting the other (the so-called " indifferent ") electrode from the lumbar region of the spine to the frontal bone.

In the second place when the unipolar electrode was placed on the surface of the pyramidal lobe of the cerebellum, and surrounded by either (1) a copper ring, or (2) the same ring covered with absorbent wool, or (3) a circle of amadou, the response was in each case very greatly diminished, *i.e.*, to about one-third of its former value.

An additional important (physiological) point is that even in all excitations of the free surface of the cortex with the marked escape to the trapezial group just described, we never, except when the localizing electrode was placed on or close to the paramedian sulcus, observed unequivocal concurrent movements of the eyes or conjugate turning of the head. The reason for the positive result occasionally obtained from the paramedian sulcus region must now be considered, and will be found to depend upon the anatomical conditions of the region which enable the stimulus to reach the subcortical structures most readily at this particular point.

The paramedian sulcus, which is so strongly marked in the carnivora and well developed in the macacque monkey, is a deep furrow filled only with loose pia mater. The cortex of the ends of the folia of the vermis, and to a similar degree of those of the paramedian lobe, ceases close to the surface of the organ; consequently the white fibres leading to the subjacent nuclei are, at this point, actually freely exposed within 2 mm. of the surface (*see* fig. 30).

Indeed in the dog and cat, where the pyramid constitutes the extreme sigmoidal flexure of the vermis, it can be seen with the operating lenses that the white fibres are often actually exposed on the free surface of the organ. In such a case obviously the response to excitation at that point would not be of cortical but nuclear origin.

The positive effects from excitation of the paramedian sulcus, which Nothnagel, Ferrier, and Hitzig have found comparatively easy to obtain, and which we also have seen, are therefore more correctly explicable as due to stimulation of the nuclei and not of the cortex.

A simple demonstration of the fallacious evidence yielded by unipolar excitation is given by first obtaining the usual false trapezial response with the unipolar electrode, and then immediately changing this for bipolar electrodes with the same coil; the result is immediate absence of any muscular contraction.

Our general conclusions from the whole of these facts are as follows

(1) The unipolar method of excitation is not accurate for investigation of the localization of function in the cerebellum.[1]

[1] While this paragraph was being composed a second communication by Lourié [10] appeared, also proving that the unipolar excitation gave results which were wholly explicable as escape of current, and therefore that the above-stated conclusion is true.

(2) The bipolar method of excitation shows that the cortex cerebelli is not like a "motor" centre intrinsically excitable to the electric stimulus.

The cortex cerebelli is therefore in accord with Edinger's views to be considered wholly as a sensory organ which is in relation with certain lower, *i.e.*, basal centres, viz., the dentate, roof and emboliform nuclei these act as the motor equivalent to the sensory representation in the cortex.

We have shown before (*Brain*, 1905) that the anatomical architecture of the cerebellum exhibits no provision of direct efferent paths from the cortex except to the neighbouring nuclei, therefore our present conclusions regarding the functional activity of these two great divisions of the small brain are in full accord with the anatomical facts.

Relative Excitability of the Cortex Cerebelli compared with that of the Cortex Cerebri.

The question of the comparative excitability of the cerebellar and cerebral cortex respectively is interesting from the general physiological aspect, and although the two organs are commonly regarded as similar in design it seems to be forgotten that the structure of the cerebellar cortex is very specialized and not like that of any other nerve centres, *e.g.*, cerebral pallium, which have been similarly investigated.

Assuming the commonest movement represented in the cerebellum to be that of deviation of the eyes, it is worth while to compare the degree of response when the cerebrum and cerebellum are respectively excited. Reference back to the table on p. 118 shows that the response which was readily evoked from the cortex cerebri by a stimulus of 100 units is hardly to be obtained from the cerebellum until such a strong stimulus is applied that it obviously excites the nuclei of the cerebellum directly, and indeed all nuclei in the neighbourhood.

It will, of course, be conceded that while every sensori-motor centre must be excitable, notable differences of degree of excitability exist even between those in the cerebral cortex: *e.g.*, the visuo-sensory occipital cortex cerebri compared to that of the præcentral gyrus. It appears to us that a parallel though greater functional separation exists between the cortex cerebelli and the intrinsic nuclei. Consequently whatever be the kinds of movements represented in the cortex cerebelli in their preliminary sensory stage, it is not probable that they are localized in the manner generally understood as motor localization in the cerebrum.

There are, moreover, two more points which in our opinion add weight to the view we are now pressing, viz., that the cortex cerebelli ought not to be regarded physiologically as of the same class of nerve centre as the cortex cerebri.

These two points are (1) stimulation after-effects, (2) intra-vital methylene blue reduction, and must be considered separately.

(1) *Stimulation after-effects.*—Perhaps the most striking feature of difference between the functions of the cerebral and cerebellar mechanisms as a whole is that while the cerebral excito-motor cortex is so essentially productive of very gross after-effects (epilepsy), excitation of the cortex of the cerebellum is not followed by any such phenomena. It is the consideration of the absence of this mode of discharge of nerve energy that led us to a series of experiments with another vital test, viz., that of methylene blue by Ehrlich's method, since the experience of one of us (V. H.) of a large series of experiments in 1893 showed that the cerebral cortical discharge (as originally discovered by Ehrlich) caused an active reduction of the blue in proportion to the degree of development of the epileptic after-effect.

(2) *Comparison of the cerebral and cerebellar intra-vital blue reaction.*—Before stating the contrast between the two organs which we have found, it is necessary to point out that, as shown by one of us and by Eve, there is a slight but distinguishable reduction of methylene blue by a strong (*i.e.*, hypermaximal for excitation of the cortex) faradic current between electrodes 2 mm. apart. But in this method of investigating the cerebral cortex the most striking feature of the activity of the nerve centre is that apart from any slight change due to the current itself the blue colour only materially fades out when the epileptic discharge commences, and then the nerve centre, the seat of the excitation, is left pale white. The method thus offers a valuable means of physiological comparison between the cerebral and cerebellar cortex respectively.

In our experiments specially on this point we have investigated the excitation of these two parts of the encephalon in dogs and cats. The total quantity of 5 per cent. solution of methylene blue injected intravitally has been on the average 400 c.c. to 500 c.c. when employed subcutaneously, or about 60 c.c. when infused into a vein direct.

Stimulation of the cortex cerebelli produced either no change in its blue tint or a slight and doubtful one, and offered a strong contrast to the clear paling on exciting the "motor" region of the cortex cerebri. It follows, therefore, that according to this evidence there is no

maximal outflow of energy from the cerebellar cortex comparable to that of the cerebral "motor" cortex.

(3) *Relative excitability of the cortex cerebelli compared to that of the nuclei cerebelli and efferent tracts therefrom.*—Perhaps the most concrete result of our method of investigating the cerebellum is the revelation of the motor functions of the intrinsic cerebellar nuclei as demonstrated by excitation. As already stated the negative result of bipolar excitation of the cortex cerebelli gradually changes into a positive effect as the needle passes forwards among the axones of the Purkinje cells running to the nearest nucleus until the stimulus is directly applied to the nucleus itself, or to the paths and tracts issuing from it when the result becomes maximal with even a very weak excitation.

The full detail of the representations of function which this method has revealed in the cerebellar nuclei we will give in Part II. of this communication.

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Dedicated to Professor Edinger on the occasion of the opening of his new Laboratory.

ON THE CONNECTION OF THE INFERIOR OLIVES WITH THE CEREBELLUM IN MAN.

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AND

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ALTHOUGH it is well known that atrophic changes may occur in an inferior olive secondary to lesions of the contralateral half of the cerebellum there are, as far as we know, no direct observations on the regional relations of these two parts.

The investigations of Lewandowsky [7], van Gehuchten [2] and others by the Marchi method have made it practically certain that the fibres which connect the inferior olives with the cerebellum are entirely cerebellopetal; this has been confirmed by the exact observations of Yagita [12], who has recently shown that in the rabbit practically all the cells of the one olive undergo reactionary chromatolysis when the opposite corpus restiforme has been cut across, while in the olive of the same side as the lesion changes are found in a small proportion of the cells only. From these facts, therefore, the conclusion may be drawn that the fibres which connect the inferior olives with the cerebellum are entirely olivofugal, and that the atrophy of the olivary cells which was first described by Meynert, and has since then been frequently observed after both experimental and pathological lesions of the cerebellum, is directly due to destruction of these fibres.

The portion of the cerebellum in which these olivo-cerebellar fibres terminate has not been, however, definitely determined; this is evident

from the following short review of the more important of the papers which have recently dealt with the subject.

According to Thomas [11] these olivo-cerebellar fibres terminate only in the cortex of the cerebellum, and have no direct connection with the dentate or its other nuclei. In the cat he found that the majority of them end in the vermis, some after decussation in the middle line. He thinks it probable that in man, owing to the greater development of both the inferior olives and the lateral lobes of the cerebellum, these two parts may be directly connected.

According to Klimoff [5], on the other hand, the olivo-cerebellar fibres which enter the cerebellum through the one corpus restiforme terminate in both the vermis and the lateral lobes, and chiefly on the same side.

Keller [4] traced the olivo-cerebellar fibres in the cat only to the posterior portion of the superior vermis. Some of them he saw decussating in the cerebellum. The roof nuclei may receive collaterals, but few, if any, fibres end in the dentate nuclei. He was unable to trace any fibres into the lateral lobes of the cerebellum.

Probst [8] also produced experimental lesions in the neighbourhood of the inferior olives. He found that the only cerebellopetal fibres which degenerated terminated in the anterior and the posterior portions of the superior vermis.

Lewandowsky [7], despite the large amount of experimental material which he possessed, could only come to the conclusion that the olivo-cerebellar fibres end chiefly in the lateral lobes and flocculus; he could not determine with certainty whether any entered the vermis, as degeneration of these fibres was always associated with degeneration of the spino-cerebellar tracts which end in the vermis.

Van Gehuchten [2], although convinced that the connection of the inferior olives with the cerebellum is entirely olivofugal, was not able to ascertain definitely where the olivo-cerebellar fibres terminate in the cerebellum, as when he obtained degeneration of these fibres by lesions in the neighbourhood of the olives other cerebellopetal fibres were also injured.

Several years ago Risien Russell [9] came to the conclusion that the olivo-cerebellar fibres terminate not in the cerebellar cortex but in the dentate nuclei, as in the cerebellum of a puppy which he examined the pathological changes were limited to the cerebellar cortex and the inferior olives were intact. As, however, the cortical abnormality was due to a developmental anomaly and not to a degenerative process this

conclusion was scarcely justifiable. Babinski and Nageotte [1] have recently come to the same conclusion. They examined a case in which there were several foci of softening in the medulla, due to syphilitic vascular disease, and observed degenerated fibres which ascend to the cerebellum through the corpus restiforme, bend over the dentate nucleus and end in this and in the embolus, while none could be followed into the cerebellar cortex. Laignel-Lavastine [6] also supports this view; he examined a case in which there was an old focus of softening in the white matter of one lateral lobe of the cerebellum and found atrophic changes in the contralateral olive, but as the primary lesion involved the corpus restiforme in the cerebellum it is difficult to see how he came to this conclusion. The conclusions of the French authors can be of little weight when compared with the results obtained by more exact experimental lesions. In the case described by Babinski and Nageotte the interruption of the fibres involved in the lesions was evidently very incomplete, while Laignel-Lavastine's conclusions were arrived at by the examination of material by Marchi's method two years after the occurrence of the primary lesion, when a large proportion of the degeneration products which are revealed by this method must have been removed.

The discrepancies between the conclusions of these different authors are evidently due to the fact that the olivo-cerebellar fibres can be traced only by the degeneration methods, and as it is practically impossible to produce an isolated lesion of them, either at their origin or in their course, when degenerated they are practically always intermixed with degenerated fibres of other cerebellopetal bundles, and especially with those of the spino-cerebellar tracts.

Our investigations have been limited to the examination of the olives in cases in which there had been destructive lesions of various portions of the cortex of the cerebellum. We have been able to utilize for this purpose the central nervous systems of all the cases with local lesions in the cerebellum which have died in the National Hospital during the past five years.

As early as seven days after the occurrence of an acute and complete destructive lesion of the cerebellar cortex chromatolytic changes may be observed in the cells of the olive on the opposite side to the lesion; the marked swelling of the cells, with disintegration of the tigroid and eccentricity of their nuclei, is very prominent even within this period, and generally persists for some weeks. Some of these swollen cells may become vacuolated, and within three or four weeks

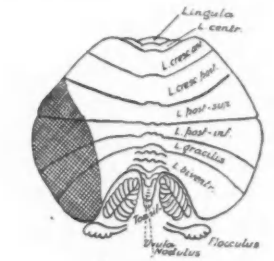
after destruction of the olivo-cerebellar fibres many of the affected cells begin to atrophy and eventually disappear. After about six or seven weeks, in our experience, the majority of the cells of origin of the olivo-cerebellar fibres which have been destroyed by an acute lesion have disappeared, and in their place a secondary proliferation of the neuroglia, and eventually sclerosis and shrinkage of the olive occur. In cases in which the cerebellar lesions had been of long standing some diminution and atrophy of the olivo-cerebellar fibres could be demonstrated, especially of those within the contralateral olive.

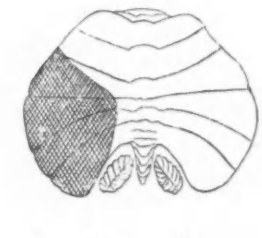
We have found that those cases in which the cerebellar lesion was acute, and in which there was complete destruction of at least some portion of the cortex, were the most suitable for our purpose. Very little or no reactionary change could be found in the cells of the olives when even the greater portion of the contralateral half of the cerebellum had been infiltrated or slowly destroyed by a tumour. This observation is analogous to the fact that the ventral horn cells of the cord may remain structurally intact when a peripheral nerve is injured by slow compression, while they undergo marked chromatolysis if the nerve is suddenly cut across, and especially if it is roughly torn out. In the greater number of the specimens we have made use of, some portion of the cerebellum had been completely destroyed, either in the removal of a tumour or by surgical exploration some time before death. In one of the cases, however, there was only a primary degeneration of the cerebellar cortex, and in another a small area of cortex had been destroyed by a carcinomatous tumour growing from the pia mater. When, however, cerebellar lesions of slow and gradual evolution had persisted for a long period before death, atrophy and disappearance of some of the cells of the opposite olive could be sometimes observed. In a few of our cases, for instance, in which part of the cerebellum had been destroyed by a slowly growing tumour and another part damaged by operative procedures a short time before death, we found some of the olivary cells undergoing these slow regressive changes and others in the state of acute *réaction à distance*.

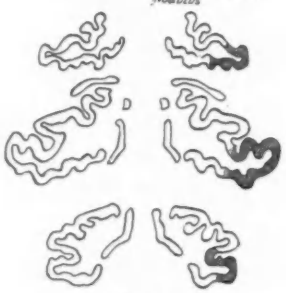
From the examination of the material at our disposal we have come to the conclusion that definite portions of each olive are connected with definite portions only of the cortex of the lateral lobes and of the vermis of the cerebellum. With regard to the flocculus we are unable to say anything, as this portion of the cerebellum was not injured in any of the focal lesions we have observed.

Case 1.—In October, 1905, an exploratory operation was performed over the left lateral lobe of the cerebellum; the dura mater was opened, but the cerebellum was not incised. The patient died seven months later. *Post-mortem* examination revealed a sarcoma of the base of the skull. It was found that the lateral margins of the postero-superior, postero-inferior and gracilis lobes of the left side of the cerebellum were completely destroyed; the rest of the cortex was intact. The softening did not extend deeply into the white matter, and only touched the postero-lateral angle of the dentate nucleus.

Olives.—The changes were limited to the extreme lateral portion of the right inferior olive. In this region at all levels there was a marked reduc-







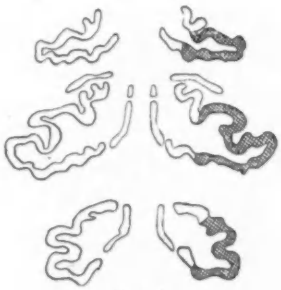


FIG. 1. FIG. 2.

The diagrams show the area of the cerebellar cortex which was destroyed in each case, and the region of the contralateral olive in which changes were present. Fig. 1 represents Cases 1 and 2; fig. 2, Cases 3 and 4.

In each diagram three different levels of the inferior olive are drawn; from above downwards, the frontal third, the middle, and the caudal third.

The slighter changes in the homolateral olives are not indicated in these diagrams.

tion in the number of the cells; some of those which remained were in the state of chromatolysis; others were very much atrophied. A few swollen cells were seen in the corresponding region of the left inferior olive. The accessory olives were intact (fig. 1).

Case 2.—In May, 1904, a tubercular tumour was removed from the lateral portion of the left lobe of the cerebellum. Seven weeks later the patient died

from tubercular meningitis. It was found that the lateral portions of the postero-superior, postero-inferior, gracilis and biventral lobules had been destroyed. The rest of the cerebellum was intact. The operative lesion did not extend down to the neighbourhood of the dentate nucleus.

Olives.—No normal cells could be seen in the lateral portion of the right inferior olive; the majority had disappeared, others were extremely atrophied and a few were chromatolytic. The extent of the affected area was approximately the same as in Case 1, but it extended somewhat further medialwards along the ventral fold.

Case 3.—A large gumma was removed from the left lateral lobe of the cerebellum in October, 1904. The patient died about two years later from renal disease. On *post-mortem* examination it was found that there was no active cerebral disease, but the greater part of the left lateral lobe of the cerebellum was absent; the only portions which remained were the anterior and posterior crescentic lobules, the medial portion of the biventral, and the tonsil and flocculus. These parts were uninjured. A considerable portion of the central white matter had been removed, and the lateral part of the dentate nucleus had been damaged. The vermis and the right lobe were intact.

Olives.—There was an almost complete absence of cells in the lateral two-thirds of the right inferior olive. The region affected was considerably greater than in Cases 1 and 2; it extended further medialwards in both the dorsal and ventral folds of the olive, but especially in the former. The rest of the inferior olive, as well as the accessory olives, were intact (fig. 2).

Case 4.—Nine days before death the left lateral lobe of the cerebellum was explored and cut into. At the *post-mortem* examination a large tumour was found in the right frontal lobe. The greater portions of the postero-inferior, gracilis and biventral lobes, as well as the lateral extremity of the postero-superior lobe, had been destroyed. The rest of the cortex was intact, but the operative incision extended down to the dorso-lateral part of the dentate nucleus.

Olives.—Practically all the cells of the lateral half of the right inferior olive were in the state of acute reactionary chromatolysis. The area in which the affected cells were found was almost identical with the area of change in Case 3. A few cells showing *réaction à distance* were present in the same region of the left inferior olive.

In these four cases in which the lesion of the cerebellum was limited to the lateral portion of one lateral lobe we found changes in the lateral portion only of the contralateral olive. We may therefore conclude that the olivo-cerebellar fibres which terminate in the cortex of the lateral folia of the cerebellum arise from the cells of the lateral portion of the opposite inferior olive. In Cases 1 and 2, in which the lateral extremity only of the cerebellum was involved,

the olivary change was considerably less extensive than in Cases 3 and 4, in which a much larger area of the cerebellar cortex had been destroyed. From this we may further conclude that the cerebellopetal fibres which spring from the lateral extremity of the one olive end in the cortex of the most lateral portions of the opposite side of the cerebellum, while those which arise from the adjoining portions of the dorsal and ventral folds of the olive terminate in the middle zone of the lateral lobe of the cerebellum.

Case 5.—At the *post-mortem* examination a small carcinomatous tumour was found in the middle of the left postero-inferior lobule. It had entirely

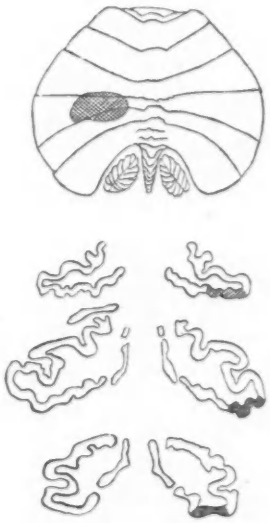


FIG. 3.

destroyed the cortex of this lobe and the neighbouring margins of the postero-superior and gracilis, but it extended only a very short distance into the white matter.

Olives.—Cells in chromatolysis were found only in the lateral end of the ventral fold of the right inferior olive. They did not extend quite to the lateral extremity of the olive (fig. 3).

Case 6.—The patient died seven days after an operation on the right lateral lobe of the cerebellum for tumour. The cerebellum was not incised, but at the autopsy it was found that a portion of its cortex had extruded through the

opening in the dura mater and had been destroyed. The portion destroyed belonged to the posterior margin of the lateral half of the postero-superior, the lateral three-quarters of the postero-inferior, and the central portion of the gracilis. The lesion was quite superficial. The tumour lay in the centre of the left lateral lobe; it compressed but did not destroy the left dentate nucleus.

Olives.—All the cells of the lateral extremity of the left inferior olive and of the lateral portion of its dorsal fold were in the state of acute chromatolysis. The rest of the inferior olive and the accessory olives were unaffected.

In Cases 5 and 6 the area of cerebellar cortex destroyed was much less extensive than in the four previous cases, and corresponding

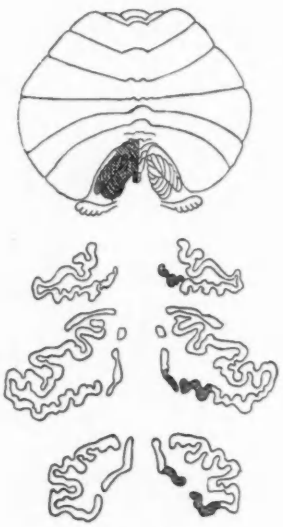


FIG. 4.

thereto the region of the olives in which changes could be observed was much smaller. In Case 5, in which the extreme lateral portion of the cerebellum escaped, the changes observed in the contralateral olive did not extend to its lateral tip; on the other hand, in Case 6, in which the most lateral folia were destroyed, the majority of the cells of the lateral extremity of the contralateral olive were in chromatolysis. These cases therefore confirm our previous conclusions.

Further, in Case 5, the lesion was practically limited to the inferior surface of the cerebellum, and the cell changes were limited to the ventral fold of the opposite olive. This indicates that the ventral fold of the olive is in connection chiefly with the inferior surface of the cerebellum.

Case 7.—This was a case of primary degeneration of the cerebellar cortex which has been already described by one of us [3]. The only portion of the cortex which escaped was that of the tonsils, the uvula and the nodule. The cerebellar nuclei were unaffected.

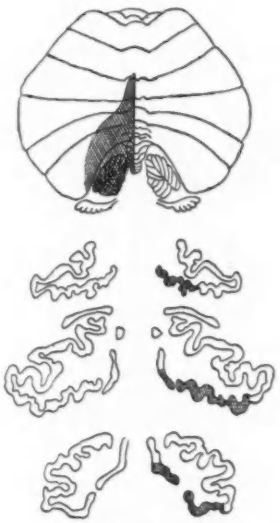


FIG. 5.

Olives.—The only portion of the inferior olives in which any cells remained were the medial ends of the ventral folds and the ventral extremities of the medial accessory olives. In the rest not a single cell could be seen, and the tissue was densely sclerosed (fig. 4; the normal parts of both the cerebellum and the olives are cross-hatched).

Case 8.—This patient had been repeatedly operated on for a cerebellar gliomatous cyst of long duration. On *post-mortem* examination of the cerebellum it was found that the inferior vermis and the declivum, as well as the tonsil and the adjacent parts of the biventral and gracilis lobes of the left side, had been destroyed.

Olives.—The majority of the cells of the ventral fold of the right inferior

olive and of the ventral extremity of the medial accessory olive had disappeared, and those which remained were atrophied and shrunken. The lateral portion of the inferior olive escaped, and the dorsal fold and the dorsal accessory olive were intact (fig. 5).

Case 9.—The patient died sixteen days after a portion of a tumour had been removed from the right lateral lobe of the cerebellum. The medial two-thirds of the postero-inferior and gracilis lobes, the greater portion of the biventral, and the medial folia of the postero-superior lobe were destroyed by the operation; the tumour had destroyed the pyramid, the tuber valvulæ and the declivum.

Olives.—There were two varieties of cell change in the olives. In the first place acute tigrolysis of practically all the cells of the ventral fold of the left inferior olive, except in its medial end; a smaller number of cells were also seen in chromatolysis in the corresponding area of the opposite olive. In the second place there was a definite numerical diminution of cells in the left medial accessory olive, and the majority of those which remained were atrophied.

In Case 7 the only portion of the cerebellar cortex which was normal was that of the nodule, uvula and tonsil; normal cells were present only in the medial portion of the ventral fold of the inferior olive and in the ventral portion of the accessory olive. We may, then, conclude that the olivo-cerebellar fibres which spring from this part of the olive terminate in that region of the cerebellum. This observation is apparently supported by the findings in a somewhat similar case reported by Schweiger [10], in which the tonsil was almost normal and the vermis was very much less affected than the cortex of the lateral lobes. According to his description the medial accessory olives were relatively intact, and from one of his illustrations at least (fig. 4) it is evident that the medial portion of the ventral fold of the inferior olive was but little affected. Case 8 also confirms this conclusion, but as the mesial portions of the gracilis and biventral lobes had been also destroyed, the area of change in the inferior olive extended further lateralwards in its ventral fold.

In Case 9 the superior segments of the inferior vermis were destroyed by a tumour, and the cells of the dorsal part of the medial accessory olive were atrophied; possibly these two regions are connected. In Schweiger's case, which has been already referred to, the whole of the vermis was relatively intact and the dorsal part of the medial accessory olive was one of the only portions which escaped secondary atrophy. In Case 8, however, the dorsal segments of the inferior vermis were also invaded by tumour, yet no changes

were observed in that portion of the medial accessory olive; this may have been due to the nature of the cerebellar lesion.

Case 10.—In 1904 a cerebellar cyst was opened through the middle of the left postero-inferior lobule. The patient made a complete recovery and remained free from symptoms for three and a half years. Owing to the recurrence of symptoms she was again operated upon in the same region, and a large gliomatous cyst was removed. She died seven weeks later. The greater part of postero-superior, postero-inferior and gracilis lobules of the left half of the cerebellum were destroyed by the last operation, and the biventral was seriously bruised. The tonsil had shrunk to one-third of its normal size, but the flocculus was intact. On the right side practically the whole of the postero-superior, postero-inferior, gracilis and biventral lobules were destroyed by a large cyst, which had also destroyed the whole of the inferior vermis.

Olives.—It was difficult to interpret the olivary affections in this case as there were at least three cerebellar lesions of different nature, duration and distribution. We observed: (1) reduction in number of cells in the lateral portion of the right olive, corresponding probably to the first operation wound; (2) a slight loss of cells and marked tigrolysis of the rest in the ventral fold of this olive, due probably to the later operative incision and the removal of a tumour from the inferior surface of the left lateral lobe; (3) atrophic changes in the whole of the ventral fold and in the lateral half of the dorsal fold of the left inferior and the medial accessory olive, secondary probably to the destruction of the right side of the cerebellum by the cyst. The chief value of this case is that the only part of the cerebellum which was uninjured was the frontal portion of its superior surface, while normal cells were found only in the dorsal accessory olives and in the medial halves of the dorsal folds of the inferior olives.

The superior vermis, the central, and the two crescentic lobules of the cerebellum escaped injury in all the focal lesions we have observed; in Case 10 these were practically the only portions of the cerebellum which were intact; the mesial halves of the dorsal folds of the inferior olives and the dorsal accessory olives were also unaffected in all these cases. In Case 7, on the other hand, the cortex of the whole of the superior surface of the cerebellum was degenerated, and these portions of the olives contained no cells. The conclusion, therefore, appears justified that the olivo-cerebellar fibres which arise from the dorsal accessory olive and the medial half of the dorsal fold of the inferior olive terminate in the superior vermis and the superior surface of the cerebellum.

We recognize that our conclusions from these observations cannot be final, as the lesion was not in every case limited to the cortex

of the cerebellum, and some of the olivo-cerebellar fibres destined for undamaged portions of the cortex may have been injured in their course through the subcortical white matter. But we could exclude this in a certain number of our cases. It appears to us certain, however, that there is a definite regional relationship between the different portions of the cortex of the cerebellum and the various parts of the inferior and accessory olives. We cannot, with certainty, say that the olivo-cerebellar fibres terminate in the cortex of both the lateral lobes and of the vermis, as we have no cases in which the vermis alone was damaged or in which the lesion was limited to, but included the whole of, the lateral lobes. It appears to us probable that it is so.

In one of our cases the primary disease was limited to the cortex of the cerebellum (Case 7), and in others the lesion involved only the immediately subcortical white matter. In these cases practically all the cells of some one or other portion of the olives had undergone definite changes. We can therefore conclude that all the fibres which the olives send to the cerebellum terminate in the cortex and not in the central nuclei. Further, as we have found complete absence of cells in all portions of the olives in one or other of our cases we may draw the conclusion that all the fibres that take origin from the cells of the olives terminate in the cortex of the cerebellum.

The connection of each olive is chiefly with the contra-lateral side of the cerebellum, but in all our cases in which the lesion was recent and had produced chromatolysis of the olivary cells this change could be detected in a small proportion of the cells in the corresponding portion of the olive homolateral to the cerebellar lesion. This fact has been already ascertained by Yagita and others in experiments on animals.

Conclusions.

(1) All the cells of the inferior and the accessory olives send their axis cylinders to the cerebellum.

(2) The connection of each olive is chiefly with the contralateral half of the cerebellum.

(3) The olivo-cerebellar fibres terminate in the cortex of the lateral lobes, and probably also in the vermis of the cerebellum. Certainly no large proportion of them end in the cerebellar nuclei.

(4) There is a definite regional relationship between the different portions of the inferior and accessory olives and the different areas of the cortex of the cerebellum (fig. 6) : (*a*) the lateral portions of the

olives are connected with the lateral portions of the opposite side of the cerebellum; (*b*) the medial ends of the inferior olives and the medial accessory olives send fibres probably to the vermis and the mesial portions of the lateral lobes of the cerebellum; (*c*) the dorsal fold of the olive is in connection chiefly with the superior surface of the cerebellum; (*d*) the ventral fold of the olive sends the fibres chiefly to the inferior of the cerebellum.

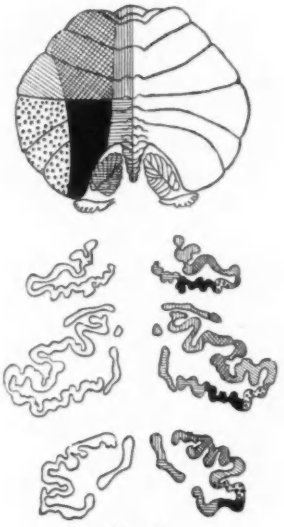


FIG. 6.

A composite diagram to illustrate the Conclusions. The regions of the cerebeller cortex and the inferior olives which correspond are indicated by similar markings.

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THE EFFECT OF STRUCTURAL CHANGES CONNECTED WITH THE DEVELOPMENT OF BINOCULAR VISION ON ASSOCIATED MOVEMENTS OF THE EYES.

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In the evolution of binocular vision from the divergent eyes of primitive vertebrates a considerable change takes place in the anatomical position of the eyes in the skull, and, as a matter of simple mechanics, this change of position must have a marked effect on those associated or conjugate rotations of the eyes which had become habitual. In the primitive vertebrate the eyes look in opposite directions in the same axis at right angles to the spine; this is approximately the condition in many mammals—the armadillo is a good example—and the majority of birds, reptiles, and fishes. If we compare an animal of this class with a typical example of those which possess binocular vision, like the monkey or owl, the change in the position of the eyes in the latter is very marked, and it is evident that the difference in position may considerably modify the mutual relations of the rotations of the eyes on their own axes, and that a movement which is a conjugate rotation in one position may become a reverse rotation in the other. It will be seen presently that conjugate rotation in divergent eyes in the frontal and sagittal planes becomes reverse rotation in the position of parallel vision, while conjugate rotation in the horizontal plane remains conjugate in both positions. In the course of its evolution, therefore, the binocular animal was confronted with the alternative of continuing the old conjugate rotations of its eyes, with the result that two-thirds of these movements would be no longer conjugate but reverse, or of discarding the old habits and substituting new combinations. In applying the word selection to such cases as this, the idea of choice which it suggests is not wholly figurative. The supersession of an old habit by a new one must, for a time, involve the exercise of purposive direction, and how long such direction is required before the new movements become

perfectly automatic; what is the relative status of centres which initiate a new combination and those which suffice for an old-established automatism; how long does a tendency persist to revert to the old habit when the directing influence is withdrawn; and does any such tendency still exists in binocular animals. These are questions which naturally suggest themselves, and a still more interesting one is, How did the new habits, when acquired, become hereditary? For as it is anathema to admit the possibility of acquired characters being transmitted, the only alternative seems to be that as soon as phylogenetic structural changes made it desirable that the simultaneous contraction of both superior recti should be substituted for the old association of one superior with the other inferior rectus, the advantage of this little change became so prodigious and assertive that not a single individual was permitted to live unless his germ-plasm enshrined the potential of the new combination and excluded the old; all the rest were exterminated by the agencies which eliminate the unfit—and no men or monkeys can now look up with one eye and down with the other at the same time, as their ancestors and ours always used to. We are accustomed to regard evolutionary changes as very gradual, perhaps imperceptible, but it does not appear that this one can have been so; originally one superior rectus always acted with the inferior rectus of the other eye; when it gave this up it went into partnership with the other superior rectus in simultaneous rotations of the eyes in the sagittal plane—it must have acted with one or the other; no transitional stage appears to be possible.

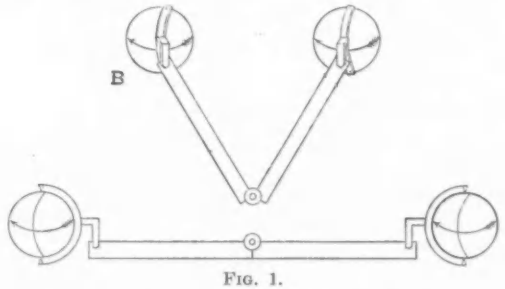
The effect of changes of position of the eyes on their associated movements is a question of simple mechanics which has not received much attention as far as I know, and it is worth further consideration on its own account, and still more because it is involved in various questions of interest to biology and physiology. I propose, therefore, to examine this point more closely. It will be sufficient in discussing variations of rotation to confine ourselves to three planes, horizontal, frontal and sagittal, the application of the same principles to intermediate planes being obvious. As frequent reference may be necessary to planes, axes, &c., which are relative terms, to avoid any ambiguity and for purposes of reference, if required, it will be advisable to agree on definitions of these and a few other terms in advance. As the normal visual axes of vertebrates are generally directed to the horizon, parallel to the apparent surface of the earth, the direction of these axes in two dimensions will serve to define the horizontal plane. The frontal plane is perpendicular to the horizontal and bisects both

eyeballs, and the sagittal plane is perpendicular to both the others and bisects the skull—the definition must be extended to planes parallel to those described. The axes perpendicular to these planes will be referred to as vertical, longitudinal and transverse respectively. Conjugate rotation of two spheres or discs may be defined as simultaneous rotation in the same direction, in the same or parallel planes on the same or parallel axes. The wheels of a moving dog-cart serve as an illustration of conjugate rotation in the same direction in parallel planes on the same axis, and those of a bicycle in the same plane on parallel axes. The plane of rotation of a sphere is perpendicular to its axis. In a rotating disc or sphere a point on its periphery, regarded from its axis of rotation, moves to the right or left; that is the direction of its rotation.

The two varieties of movement of the eyes whose mutual reactions we have to examine may be compared to the double movement of the earth rotating on its axis and moving in an orbit round the sun. The eyes may rotate on their own axes in all planes, and in passing from the position seen in the armadillo to that in the monkey they may be described as traversing part of an orbit of which the centre is the chiasma and the radius the optic nerve. In binocular mammals and birds this orbit is in the horizontal plane, as in both the old and new positions of the eyes the normal visual axes are directed to the horizon. In these animals the change of position may be described as a forward movement of both eyes in opposite directions, so as to approach one another through corresponding segments of the same horizontal orbit, the centre of which is the chiasma and the radii the optic nerves; originally the optic nerves were in nearly the same straight line, but are finally brought to a V-shaped angle of about 60°, complete parallelism of the visual axes being obtained by slight inward rotation of the eyes on vertical axes. It is interesting to compare this method of passing from divergent to parallel vision with that which occurs in flat-fish like the plaice and flounder; here, instead of both eyes traversing equal segments of a horizontal orbit, one eye moves through nearly half a circle in the frontal plane towards the other eye, which is stationary. The decussation is still the centre and the optic nerve the radius of the orbit; but the most remarkable thing is that the change takes place in the life of the individual; the immature fish have divergent eyes, and as they develop the change of position referred to occurs. In the higher vertebrates the attainment of binocular vision is apparently the only object of the evolution, but in fish it seems to be merely a part of more general structural changes which render it necessary.

In the higher vertebrates the change from divergent to parallel vision is a phylogenetic evolution which has probably taken ages to complete; it is effected by moving both eyes forward through corresponding segments rather less than quadrants of the same horizontal orbit. In fish the process is ontogenetic and effected by moving one eye through nearly half a circle in a frontal orbit, which has the same centre and radius in both cases. Divergent eyes could only approach one another in the frontal or horizontal planes, and in the above we have instances of their doing so in both. We have now to consider the effect of these movements on the rotation of the eyes on their own axes, and it will facilitate description if we begin by examining the principle in a model representing both forms of movement before we apply it to animals. Like many other movements, they can be seen at a glance in a model, less easily in a diagram, while verbal descriptions are tedious and unintelligible. It is necessary to give descriptions in words, if only for reference, but I hope the diagram, rough as it is, may save some at least of the trouble of reading. The model (*see* fig. 1) consists of two globes arranged to revolve freely on axes or spindles pivoted at opposite ends of a bar hinged at its centre; the gimbals can be adjusted to allow the globes to rotate on their own axes in any plane, and, at the same time, they can be moved in an orbit, of which the hinge in the centre

Diagram of model which shows how a change in the position of the eyes affects their associated rotation. The model consists of two globes pivoted on gimbals permitting their rotation in any selected plane and fixed to the ends of a bar jointed at its centre. In the figures these parts represent the eyes, optic nerves, and the chiasma—(A) in divergent and (B) in parallel vision. The globes can be made to revolve in conjugation in the first position (A), and, while rotating, brought to the second position (B).



B Parallel vision.
Monkey.

A Divergent vision.
Primitive vertebrate—armadillo, &c.

FIG. 1.

First position (A) represents conjugate rotation in the same direction in the same horizontal plane on parallel vertical axes.

Second position (B). Remains conjugate rotation in all positions in the same horizontal plane, the segment of the orbit traversed being in the same plane as the rotation of the globes on their own axes.

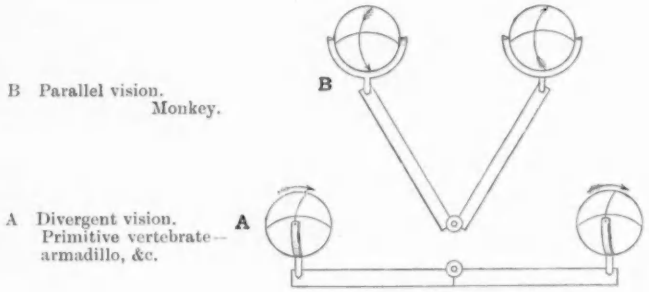


FIG. 2.

First position (A). Conjugate rotation in the same direction in the same frontal plane on parallel longitudinal axes becomes,

In second position (B), reverse rotation, in opposite directions, in parallel sagittal planes on the same transverse axis. The plane of rotation in this case is perpendicular to that of the orbit.

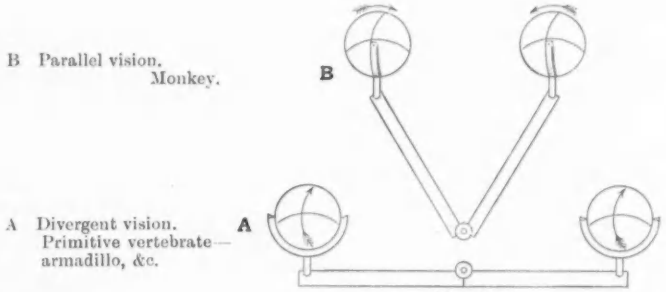


FIG. 3.

First position (A). Conjugate rotation in the same direction in parallel sagittal planes on the same transverse axis becomes,

In second position (B), reverse rotation, in opposite directions, in the same frontal plane on parallel longitudinal axes, the plane of rotation being perpendicular to that of the orbit.

represents the chiasma and the rod on either side of the hinge the optic nerves. The globes can be made to revolve in conjugate rotation, and while spinning can be moved into the positions of divergent or parallel vision. In the model it is apparent at once that if the globes are in conjugate rotation in the divergent position and they are moved to the parallel position through part of an orbit in the same plane as their own rotation, their rotation remains conjugate, *i.e.*, if they are in the position of divergent vision and rotating in the same direction in the same horizontal plane on parallel vertical axes and are moved (fig. 1), while

revolving through corresponding segments of the same horizontal orbit, to the second position (parallel vision) their rotation will still be conjugate, and it will be so in any position in that horizontal orbit. But if the plane of rotation on their own axes is perpendicular to the orbit, then the plane and axis of their own rotation change with each quadrant of the orbit they traverse (fig. 2 A). Thus if the globes are in conjugate rotation in the first position, in the same frontal plane, in the same direction and on parallel longitudinal axes, if each of them is moved forwards through one quadrant of a horizontal orbit so as to come together in front, they will be revolving in reverse directions in parallel sagittal planes on the same transverse axis (fig. 2 B). Conjugate rotation in the first position becomes reverse rotation in the second. The plane and axis of rotation have been changed in each globe after moving through one quadrant of the horizontal orbit. If both globes could be moved on through another quadrant they would be again rotating in the frontal plane on longitudinal axes as at first, and so with each quadrant of the horizontal orbit through which they are moved.

It can be seen equally easily that if the globes in the first position are in conjugate rotation (fig. 3 A) in parallel sagittal planes on the same transverse axis, and if they are moved as before through corresponding quadrants of the horizontal orbit perpendicular to their own plane of rotation till they meet in front, they will be rotating in reverse directions in the same frontal plane on parallel longitudinal axes. Here, again, the conjugate rotation in the first position has become reverse rotation in the second, as the globes have been moved through a quadrant of a horizontal orbit which is perpendicular to their own plane of rotation.

As soon as these principles are recognized in the model there can be no difficulty in applying them to the movements of the eyes in animals, the essential points of which the model represents. Rotation of the eyes may occur in any plane, but for purposes of investigation it is best to consider only three as we have done hitherto. In the model the globes can be moved through a complete quadrant, and their direction of rotation becomes absolutely reversed; in the animal the movement from the divergent to the parallel position is not a complete quadrant, and the direction of rotation, instead of becoming absolutely reversed, is only approximately so, and is, in fact, slightly oblique, one pupil moving slightly in as well as up, the other slightly out as well as down. In other respects the conditions are identical. I do not know whether many people are familiar with normal conjugate movements in divergent eyes,

but Sir Victor Horsley and I were not till we saw them in the armadillo, and then we did not recognize immediately that they were conjugate; but on reflection it was obvious that they were so, and we found them constant in other armadilloes and in ducks. The characteristic response in all animals, as far as we know, to faradic stimulation of one dentate nucleus of the cerebellum is conjugate movement of the head and eyes to the side stimulated. There are all degrees of this movement under various conditions, sometimes of the head alone, sometimes of the eyes alone, sometimes of one eye only, but the typical response is the combined movement. We found it very clearly represented in the armadillo and also in the duck. But in both when one eye moved forwards the other moved back. Of course that must be so if they both move in the same direction. Suppose the left pupil moves forwards and the right back, it is obvious that both pupils are moving to the right: the eyes are rotating in the horizontal plane on vertical axes. If we imagine ourselves observing the pupil from the axis of rotation, in both cases it moves to the right, and if the eyes were brought forwards in a horizontal orbit (fig. 1) to the parallel position, the movement would be recognized at once as conjugate rotation to the right. We made a number of observations on rotation in all three planes in the armadillo and duck with similar results, *i.e.*, in conjugate rotation in the frontal plane (fig. 2A) one pupil moved up and the other down, but the eyes were rotating in the same direction in the same frontal plane on parallel longitudinal axes—it was conjugate rotation.

Similarly with conjugate rotation in parallel sagittal planes (fig. 3A). One eye appeared to the observer to be moving in the same direction as the hands of a clock, the other in the reverse direction. They were moving in the same direction, but the observer has to look at the eyes from opposite sides, and to him the directions are reversed. The same thing can be observed in the wheels of a dog-cart, which are a good illustration of conjugate rotation in parallel sagittal planes on the same transverse axis—exactly the same rotation as we are now considering in the armadillo. Suppose the wheels of the dog-cart are both rotating as in forward movement; if the observer regards the off-wheel from that side the top of the wheel is travelling to his right, in the same direction as the hands of a clock. If he looks at the near-wheel from the near side the top of the wheel is moving towards his left—the opposite way to the other and to the clock, but the wheels are moving in the same direction: their rotation is conjugate, only the observer regards them from opposite points of view. As to the changes in associated rotations

in passing from the divergent position in the armadillo to the parallel position in the monkey, they will be obvious on referring to the model or the diagram already described. The orbit through which the eyes pass from one position to the other is a horizontal one, consequently conjugate rotation of the eyes on their own axes (fig. 1) in the horizontal plane in the first position will remain so in the second. But conjugate rotations in the frontal and sagittal planes (figs. 2 and 3), being perpendicular to the horizontal orbit in which they are moved from the first to the second position, will become reverse rotations in accordance with the rule which has been explained.

A review of these considerations appears to afford some support to the following summary of conclusions:—

(1) That animals possessing typical binocular vision, like the monkey, are descended from ancestors with divergent eyes.

(2) That these ancestors had acquired the varieties of conjugate rotation now exhibited by divergent eyes.

(3) That the conjugate rotation in the frontal and sagittal planes would become reverse rotations in the new position of the eyes, and being no longer useful were discarded, and new associated movements to produce conjugate rotations in the new position were acquired.

(4) That the supersession of the old habits by new ones must in the first instance have been directed by relatively high coördinating centres, and that, up to a certain stage of development, if this directing influence were removed there would be a tendency to revert to the old habits.

If these conclusions are at all justifiable it is possible that in animals with binocular vision some relics of that tendency still exist, and when the influence of the controlling centres is removed or interfered with the old habits occasionally assert themselves, and a reversion to the conjugate rotation of divergent eyes occurs.

The probability of this explanation of reverse rotation is apparently increased by its frequent occurrence under anæsthesia. It is frequently seen under anæsthesia alone; I do not know that it happens in animals without it, though it is possible it may do so. Sir Victor Horsley and I have records of a very large number of observations (amounting to some thousands) of movements of the eyes of various animals from stimulation of the cerebellar and other nuclei, and we have no record of skew deviation persisting in an animal after it has recovered from anæsthesia. It has often occurred under an anæsthetic before any operation has been begun, more often after stimulation of the cerebellum while the animal was still under an anæsthetic. In this respect it bears some resemblance

to the conservative contracture of muscles, both flexors and extensors, with predominance of one group or the other, which often occurs under anæsthesia when interference with afferent paths or centres has apparently deprived the directing centres of the intelligence on which they depend. Like the deviations of the eyes these contractures commonly disappear or change with recovery from anæsthesia, and, like them, often take the character of some established association of movements like progression, where the limbs of one side are flexed and of the other extended. That two forms of reverse rotation, viz., those in the frontal and sagittal planes in animals with binocular vision, should be identical with normal conjugate rotation in the divergent eyes of their ancestors is interesting, and the acquisition through long periods of time, first of a habit of associating the superior rectus of one side with the inferior rectus of the other for a useful purpose, then in response to anatomical changes of position, which themselves formed part of the evolutionary scheme of more effective vision, the reversal of this habit and its complete supersession by a new automatism, and under certain conditions, of which removal of control and interference with afferent mechanism seem the chief, a temporary reversion to the earliest habit, form a striking sequence of events which deserve consideration in any estimate of the causes of reverse rotation in parallel eyes.

NOTE ON THE EXISTENCE OF REISSNER'S FIBRE IN HIGHER VERTEBRATES.

By SIR VICTOR HORSLEY, F.R.S., F.R.C.S.

(*From the Laboratory of Chemical Pathology, University College, London.*)

MORPHOLOGICAL study of the central nervous system has for a number of years been notably advanced on the interesting structure known as Reissner's fibre by the work of Porter E. Sargent, who has shown that in the teleostean it arises in the torus longitudinalis tecti, extending thence caudally along the central canal of the nervous system, and that it is probably present in all classes of vertebrates.

For a clear survey of the literature of the subject we are also indebted to Sargent, to whose papers [3], [4], [5] reference must be made for his discussion of the character of the fibre and its anatomical structure.

The importance of its relation to the habenular region having recently formed the subject of a communication by Professor Dendy suggested to me searching the various series of sections of apes' brains in my possession as a comparison with the lower vertebrates.

The physical character of the fibre, well described by Sargent, viz., its stiff elastic recoil, causes it to be readily lost in preparing sections of the central canal of the nervous system. Hence, I have been able to find it preserved in good lengths in one animal only, *Macacus cynomolgus*, in a series of sagittal sections stained by Marchi's method, cut especially thick; in this case a considerable clot in the central canal entangled the fibre and partly secured it *in situ*.

It is, however, not only the evidence of the occurrence of this interesting structure in the higher apes which leads me to publish this note, but also that the further question of the function of the fibre deserves closer attention from neurologists.

Naturally, the greatest deference is due to the opinion of Sargent,

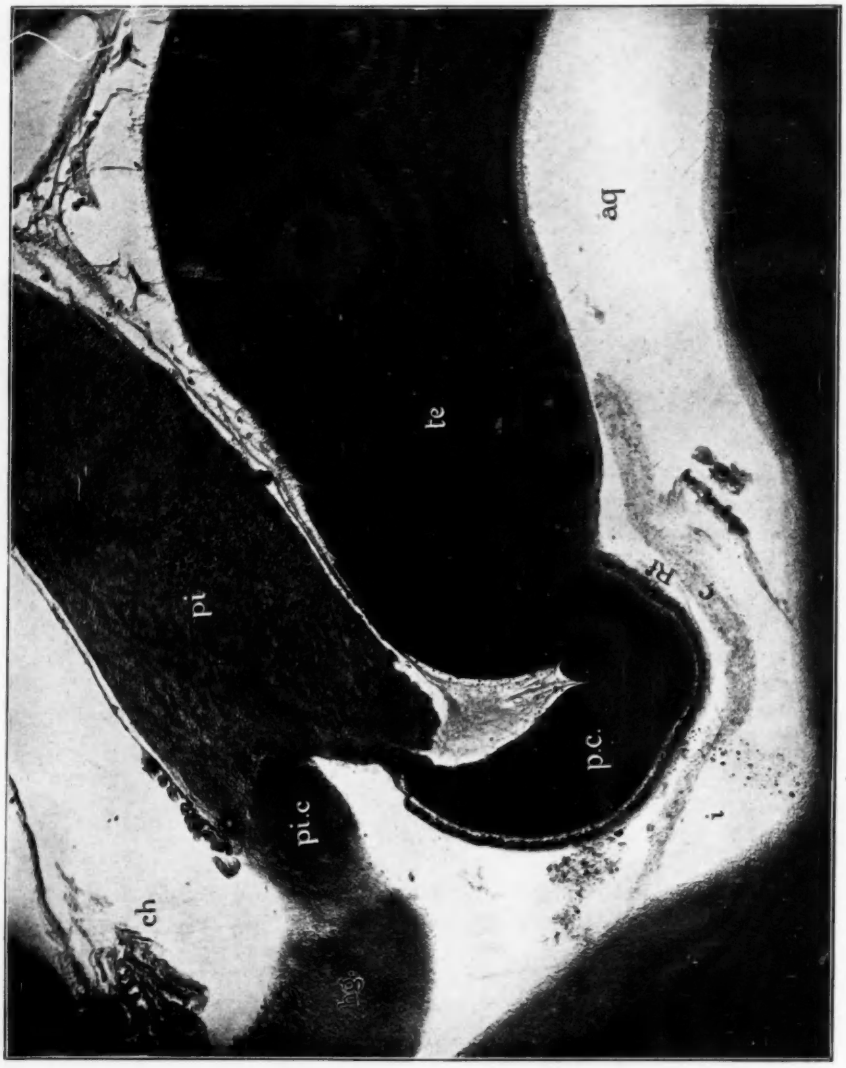


FIG. 1.

Macacus cynomolgus. Longitudinal section. ch, choroid plexus; hg., mesial surface of ganglion habenulæ; pi.c, commissura habenularis; pi, corpus pinealis; p.c., commissure posterior; te, tectum; i, iter; c, clot; Rf, letters placed at the broken end of Reissner's fibra, which extends forwards beneath the columnar epithelium as a wavy line into the clot; aq. aqueductus Fallopii.

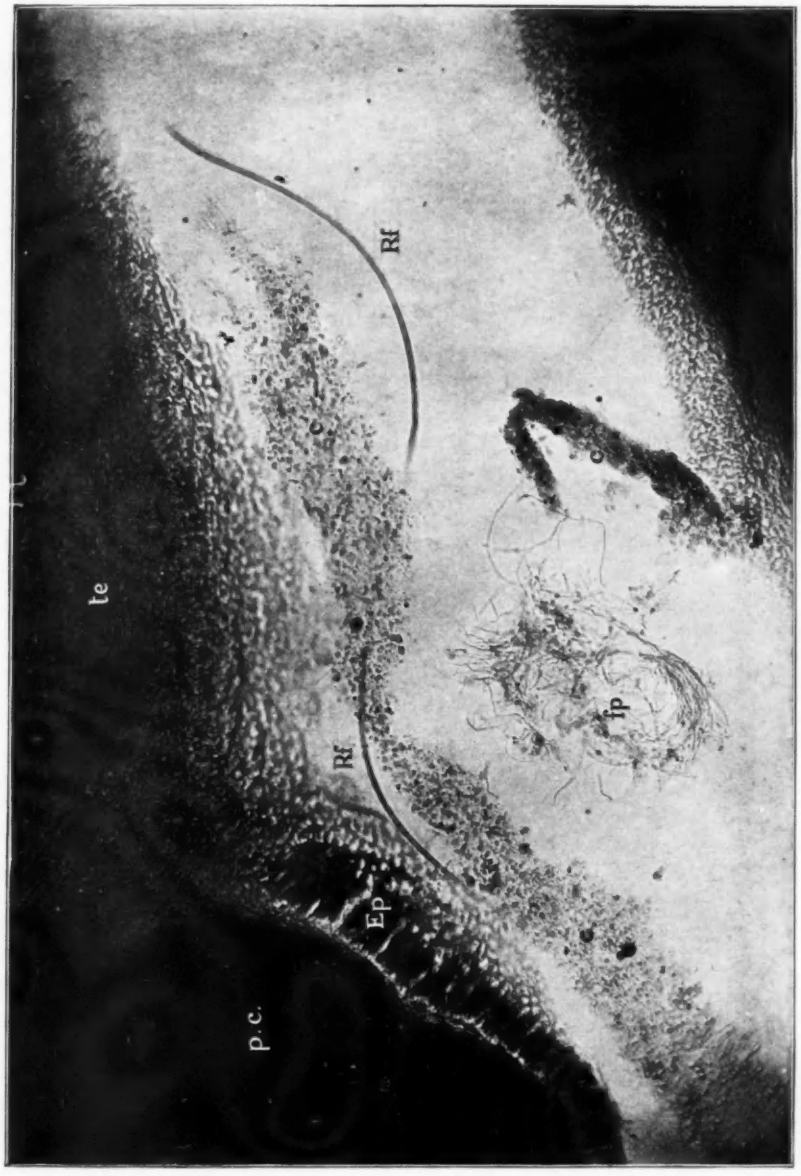


FIG. 2.

Macacus cynomolgus. Next section in the series to fig. 1. Reissner's fibre, Rf, entangled in the clot, c, continues into the aqueduct. Compare for artefacts the clots, c, c, and the filter paper fibres, f p. E p, ventral columnar epithelium (Dendy [1]).

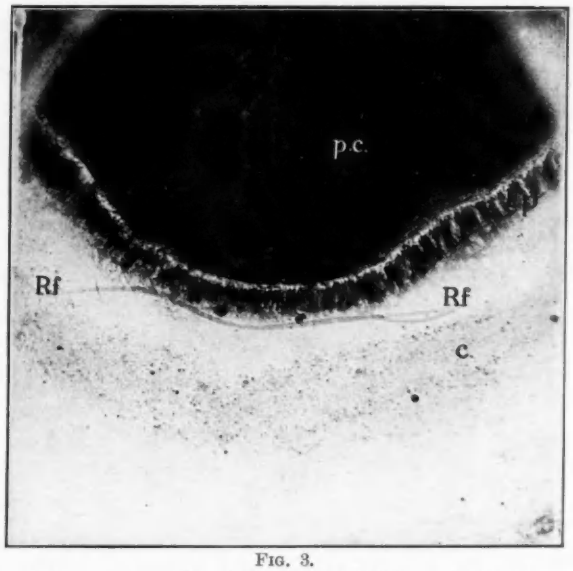


FIG. 3.

Macacus cynomolgus. Posterior half of Reissner's fibre, shown in fig. 1, more highly magnified. Lettering as figs. 1 and 2. The elastic recoil of the broken fibre is characteristically shown at the right hand end.

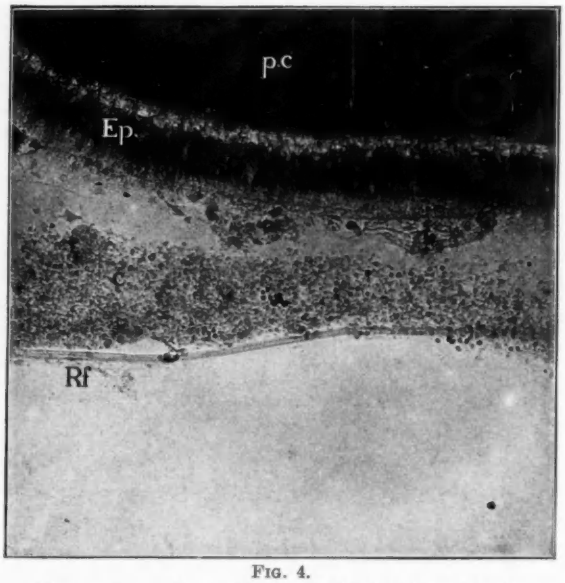


FIG. 4.

Macacus cynomolgus. The anterior half of Reissner's fibre, as shown in fig. 1, more highly magnified. The fibre, Rf, shows well (especially under a lens) the appearance of fibrillation or of a core, and reacts in staining more as an epithelial structure than a nerve fibre.

who has essentially made this subject his own; but even the study of his extremely interesting papers (especially [5]) does not produce

FIG. 5.

Macacus rhesus. Transverse section of spinal cord at the level of the first cervical segment highly magnified. The centre of the central canal is occupied by Reissner's fibre, the rest by altered blood-clot, C. The fibre shows a spot suggesting the existence of a core. The section has been lightly compressed. Ep, epithelium.

conviction that the fibre is in fact an internuncial nerve tract which rivals or even exceeds in importance the tecto-spinal system, rather

than a skeletal or ependymal structure. On this point, namely, the physiological function of Reissner's fibre, I venture to think Sherrington [6] has accepted somewhat prematurely the proofs that at present are before us of its being in the higher mammal an optic reflex nerve path.

As Sargent has abundantly established, Reissner's fibre begins by several or many roots of origin from a wide stretch of the ventral

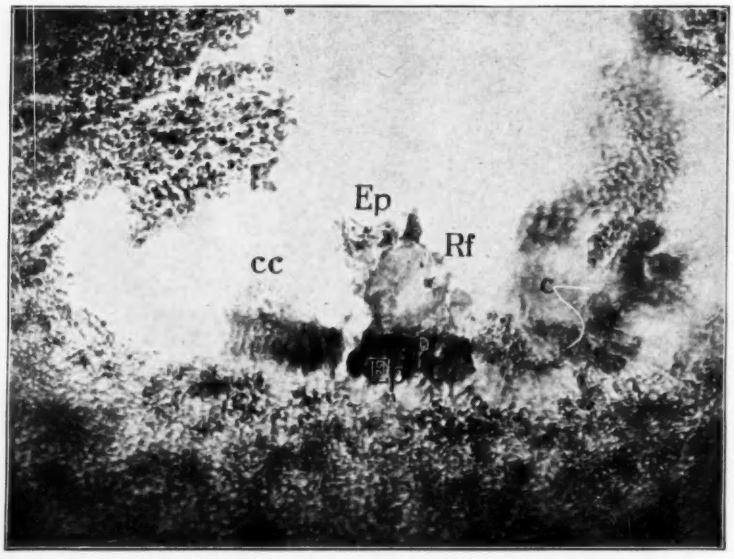


FIG. 6.

Macacus rhesus. A section close to that shown in fig. 5 dissociated by pressure, showing Reissner's fibre crushed, Rf. Its structure is seen to be unlike that of a nerve fibre, and the condensed peripheral border does not stain like myelin with the osmic acid. Ep, epithelium of central canal; cc, canalis centralis.

(ventricular) aspect of the tectum in the posterior commissural and habenular region. For its origin in the frog see [5]. He has shown that its attachments to the roof of the aqueduct extend from the habenular ganglion in front to the recessus mesocœli behind the caudal border of the posterior commissure. Here it arises in fish from the

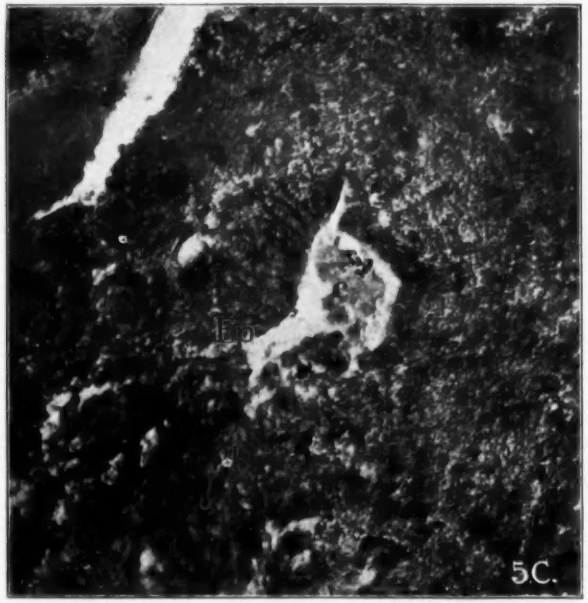


FIG. 7.

Macacus rhesus. Electrolytic destruction of the central canal of the spinal cord and of Reissner's fibre at the level of the fifth cervical segment. The ventral half of the canal is obliterated in the *débris* of the lesion, l. Some of the ependymal epithelium, Ep, is preserved. The canal is filled with clot, c, which had shrunk in fixing. The series of figures 7--13 show that though the fibre has been destroyed it does not degenerate like a nerve fibre or tract, either in an ascending or descending direction.

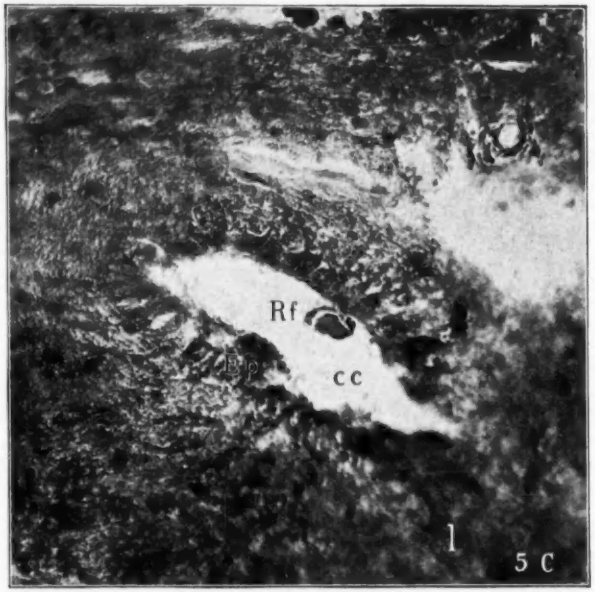


FIG. 8.

Macacus rhesus. Same experiment as in fig. 7. Section at level of upper part of fifth cervical segment showing destruction of the ventral ependymal epithelium by the lesion, l. The clot has dropped out of the central canal, c c, and Reissner's fibre, Rf, simply shrunken remains adherent to the epithelium by a little clot.

torus longitudinalis, and especially from the nucleus of large corpuscles (nidulus tectalis, Sargent), which has received various names, including the unfortunate expression *roof nucleus*. The fibre composed by the fusion of its roots of origin extends as a single structure down the iter, through the fourth ventricle and throughout the central canal of the spinal cord, giving off branches to the wall of the latter tube. The

FIG. 9.

Macacus rhesus. Same experiment as in fig. 7. Section at level of third cervical segment. The central canal shows still much injury to the epithelium, E p, while Reissner's fibre, Rf, only shows shrinkage. Nerve fibres showing myelin staining are seen at f, f.

structure of the fibre is regarded by Sargent as consisting of axones covered by a myelin sheath.

That the interior of the fibre often appears to be fibrillar is obvious, and is shown in figs. 1 to 4 (on examination with a lens), but neither the texture nor the appearance of the fibre resembles any nerve tract. Especially is this noticeable in the stiff resiliency of its structure, which

is more characteristic of an almost chitinous or skeletal structure than that of a soft nerve fibre (see also figs. 5 and 6).

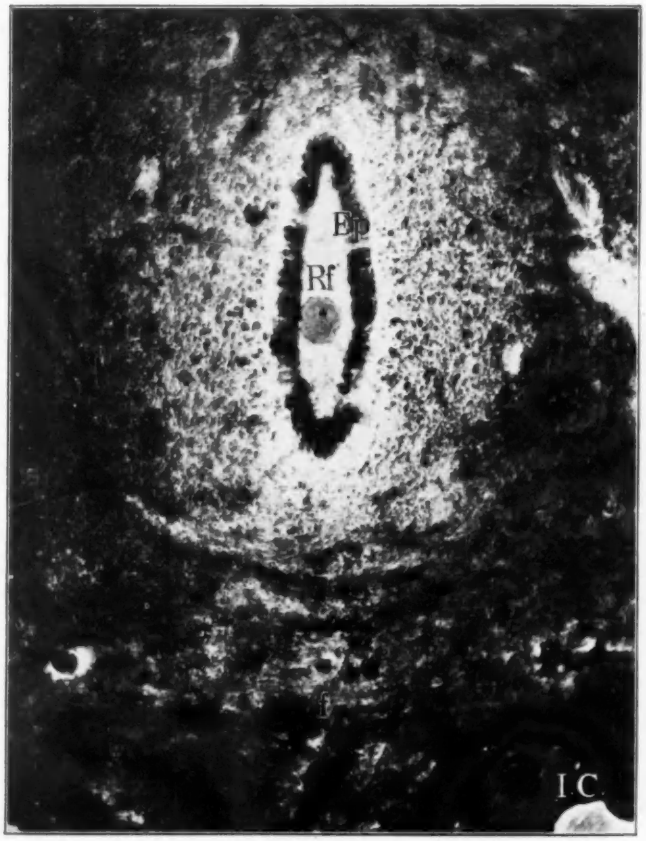


FIG. 10.

Macacus rhesus. Same experiment as in fig. 7. Section at level of first cervical segment. Reissner's fibre, Rf, is well seen in the canal, exhibiting its somewhat condensed periphery and the appearance of a core (not constant). Compare the diameter of the fibre in this figure with that in fig. 13.

As regards the existence of a myelin sheath, it is evident from the photographs that the osmic acid in fact stains the outer, or

indeed any part of the fibre, less intensely than the normal nerve fibres, and the same is observable in other animals (*Macacus rhesus*; three individuals).

Moreover none of the figures given by the various authors writing on this structure appear to me to confirm the view that the outer part of the fibre is a medullary sheath, and this point, as well as the

FIG. 11.

Macacus rhesus. Same experiment as in fig. 7. Section at level of lower border of fifth cervical segment. The epithelium of the central canal has been slightly injured over one-sixth of its circumference. Reissner's fibre, R f, is buried in the swollen epithelium. At b is a blood-clot, the hæmoglobin content of four or five red corpuscles being fused into the black mass in the centre. Reissner's fibre is unaltered, *i.e.*, not "degenerated."

central connection and origin of the fibre, must receive reinvestigation, at any rate before we can assume that the fibre is in the higher vertebrate more than a residual structure.

Finally, I have recently obtained evidence which appears to me to be inexplicable if the fibre is to be regarded as a nerve bundle. This is the

crucial test of degeneration. In a research which I am carrying on with Dr. McNalty, and in which I have made minute electrolytic lesions in the interior of the spinal cord, causing clots in the central canal and so fixing the fibre *in situ*, the following result has been obtained in a *Macacus rhesus*. The lesion destroyed in this instance the fibre at the

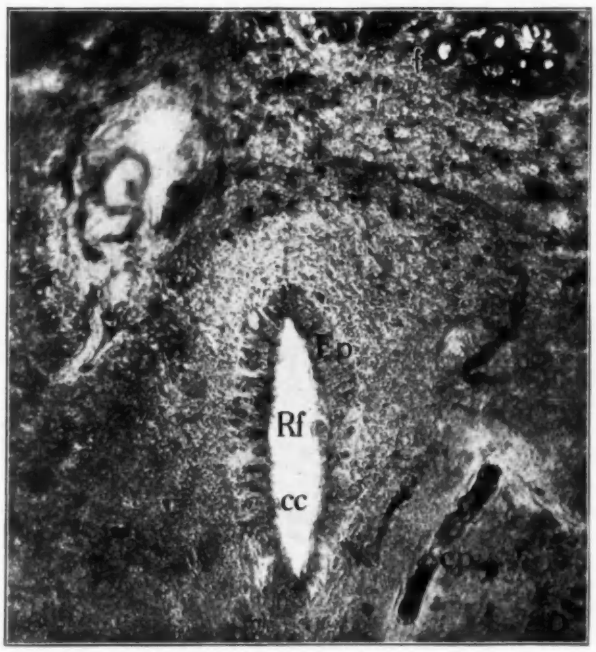


FIG. 12.

Macacus rhesus. Same experiment as fig. 7. Section at level of the second dorsal segment. Reissner's fibre, Rf, of normal appearance, lies between Rf and the ependymal epithelium. f, normal nerve fibres deeply stained with the osmic acid; cp capillary blood-vessel; cc, canalis centralis.

level of the fifth cervical segment (fig. 7), but neither upwards nor downwards from this point does the fibre exhibit any degenerative or abnormal changes, except that of moderate shrinkage from the fifth cervical to the third cervical segment—parallel, in fact, to the longitudinal extent of the electrolytic lesion (*see* figs. 7 to 13).

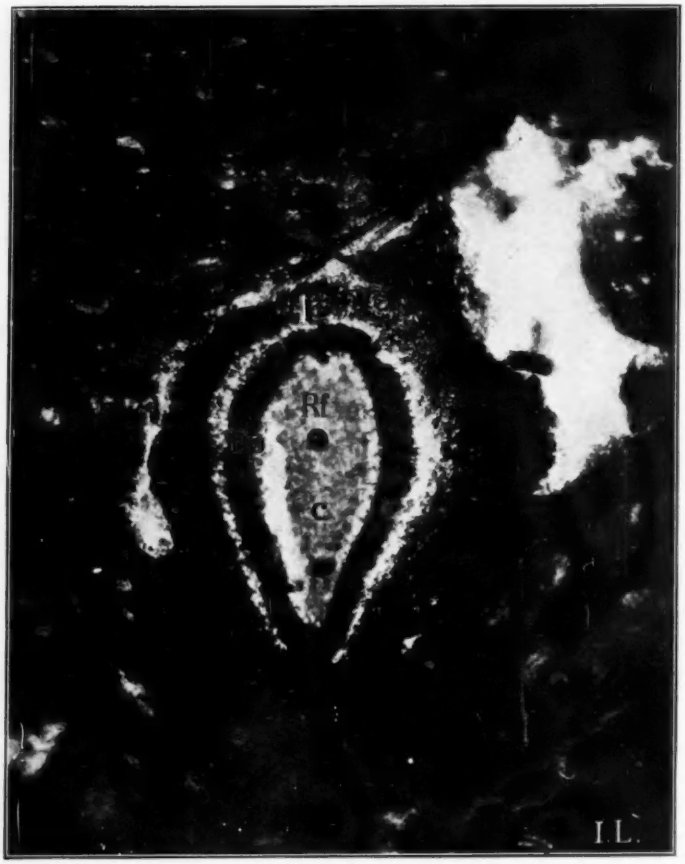


FIG. 13.

Macacus rhesus. Same experiment as fig. 7. Section at level of the first lumbar segment. The central canal is filled with clot, c. Reissner's fibre, normal in appearance and size, is seen below Rf. The tapering of the fibre (Sargent) from the first cervical (fig. 10) to the first lumbar segment is well shown in this series. Ep, epithelium.

SUMMARY.

(1) Reissner's fibre is present and well marked in *Macacus cynomolgus* and *rhesus*.

(2) Reissner's fibre in its normal structure and in its not reacting to injury does not resemble a nerve fibre or tract.

Literature.

[1] Dendy. *Proc. Roy. Soc.*, vol. lxix., p. 485; *Science Progress*, No. 6, 1907.

[2] Nicholls. *Nature*, February 13, 1908, p. 344.

[3] Sargent. *Anatom. Anzeig*, 1900, Bd. xvii., S. 32 (for literature and general course of the fibre).

[4] *Ibid.* "Mark Anniversary Volume," New York, 1903, p. 399 (for description of the torus longitudinalis and origin of the fibre).

[5] *Ibid. Bull. Mus. Comp. Zool. Harv. Coll.*, 1904, vol. xlv., No. 3, p. 129 (principal paper; full title: "The Optic Reflex Apparatus of Vertebrates for Short Circuit transmission of Motor Reflexes through Reissner's Fibre, its Morphology, Ontogeny, Phylogeny and Function.—Part I. The Fish-like Vertebrates.")

[6] Sherrington. "The Integrative Action of the Nervous System," 1906, p. 329.

A CASE OF AMYOTONIA CONGENITA.

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E. B., a female infant aged 14 months, was brought to the Hospital for Sick Children, Great Ormond Street, on July 15, 1907. The mother complained that the child was flabby and drowsy. A doctor had told her that the baby was smaller than it should be and was suffering from rickets.

Born at full term, the child was breast fed until 11 months old; she was then weaned and fed on milk, bread and butter, and gravy. She weighed 10 lb. at birth and 17 lb. at 14 months old. The mother had to have chloroform when the child was born, but as far as she knew no instruments were used.

The first thing noticed to be wrong with the child was that it did not begin to sit up at 3 months old as the other two children had done. It was not until 13 months old that any attempt to sit up was made. The child's legs had always been flabby and loose. There had never been any fits, and no trouble had occurred with the bowels or digestion, except that occasionally the motions had a strong smell. When 12 months old the baby had an attack of measles, and since then she has suffered somewhat from cough.

The mother had been married six years, and had two other girls, aged 5 and 3. Both were strong and healthy. There was no history of nervous disease in either the mother's or father's family.

Present condition.—The child is rather small for her age, but is well nourished. Her intelligence seems normal. The skin is smooth and healthy. The head measures 17½ in. in circumference, and the anterior fontanelle is almost closed. The bones are normal and there is no enlargement at the epiphysial lines. The heart and lungs are normal, and neither the liver nor the spleen is enlarged. The abdomen is not unduly protuberant.

Profound changes are found in the condition of the nervous system.

The calves are soft and velvety to the touch, and it is impossible to define the outlines of the muscles when they contract, either voluntarily or on electrical stimulation. In the lower limbs no definite muscle groups are affected, but both the extensor and flexor muscles of the legs and the extensors of the thighs are soft and flabby. The hamstrings and the adductors of the thigh do not seem to be affected and their surfaces can easily be defined beneath the skin when they contract. Neither the abdominal nor the intercostal muscles are affected, and the movements of respiration are quite normal. There is a kyphotic curve extending from the top to the bottom of the spine, and even at 14 months old the child cannot sit up without help. There is no winging of the scapulæ, and the outline of the deltoid muscle can be felt beneath the skin when it contracts. The other muscles of the arms, forearms and hands are wasted, soft and flabby. The muscles of the neck are weak and the child's head often wabbles over to one side. The facial muscles are unaffected.

The loss of bulk of the muscles is considerable, but is not of the extreme degree seen in the dystrophies or in muscular atrophies of spinal origin. Muscular power seems everywhere less than normal, but the child can grasp firmly. The most marked feature is a loss of tone in the muscles, so that an abnormal degree of passive movement is possible at the various joints. Thus the dorsum of the foot can easily be made to touch the shin without causing the child any pain. A slight degree of genu recurvatum can be produced, the amount of hyperextension being limited by the ligaments of the joint. The extreme mobility at the ankle is well shown in fig. 1. The dorsum of the hand can be bent backwards so as to touch the extensor surface of the forearm, and the forearm can be slightly hyperextended. These extensive passive movements must imply a corresponding enlargement of the joint surfaces, but possibly this occurs secondarily to the laxity of the muscles. Fig. 2 shows the hyperextension at the wrist and elbow.

The electrical reactions in the muscles are interesting. Faradic excitability is diminished. Measured by Dr. Reginald Morton's faradic alternator, a contraction can just be obtained with a current of 1·4 ma., whereas a normal muscle gives a brisk response with 0·6 ma. Another feature is the ability of the child to bear strong faradic currents without discomfort. Thus she makes little remonstrance when the muscles are tested with a faradic current of 4 ma., a strength which on this instrument would make a normal child scream with pain. Galvanic excitability is likewise diminished, but the response is quite a brisk twitch and not

at all sluggish. Thus contraction is first obtained with a current of 2·5 ma., whereas from normal muscle a brisk response can be obtained

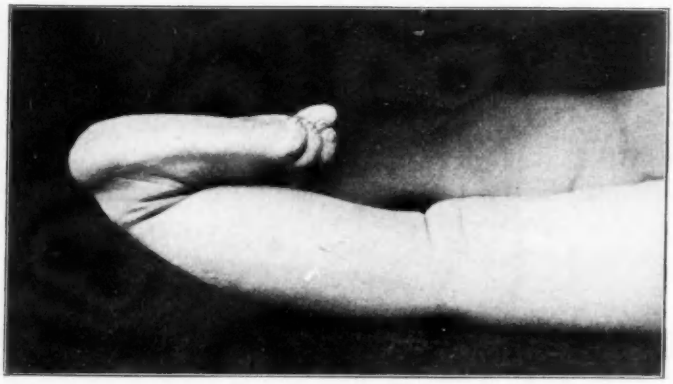

FIG. 1.

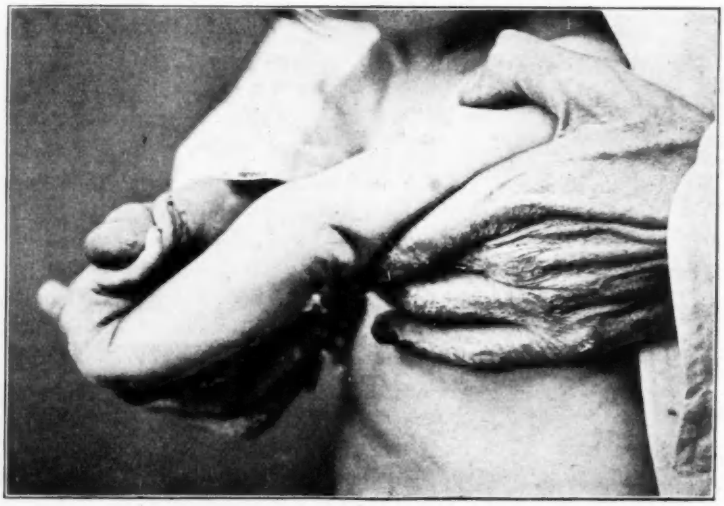

FIG. 2.

with 1 ma. There is no alteration in the polar reactions, the kathodal closing contraction being as strong as the anodal closing contraction.

There is no alteration in the faradic or galvanic excitability of the nerve trunks.

Sensation.—Sensation to touch is normal. When pricked with a pin the child begins to cry and strongly resents it. This is in sharp contrast to her apathy when tested with the strong faradic current, and suggests that possibly the peripheral sensory mechanism in the muscles is undeveloped, while in the skin it is not affected.

Reflexes.—The knee-jerks were obtained on both sides, but no response could be elicited on stroking the soles.

Progress.—The child was treated by massage and tonics. When seen in November, 1907 (*i.e.*, when 18 months old), she had greatly improved. She could sit up alone and also made an attempt to stand. When doing this the dorsal kyphotic curve disappeared and there was some lordosis in the lumbar region of the spine. She could say a few words and seemed to be progressing favourably.

Remarks.

The absence of any sign of involvement of the brain and spinal cord, the general distribution of the lesion and the character of the electrical reactions, point to the muscles themselves as being the seat of the disease. The distribution of the affected muscles is markedly different from that seen in the muscular dystrophies. In the latter the muscles of the hip and shoulder girdles are generally affected, while the muscles of the forearms and legs are rarely involved. Moreover the dystrophies begin to show symptoms at a much later age than in the case of this child, in whom weakness was noticed at 3 months old. There remains the possibility that the muscular weakness may be due to some general condition such as rickets, in which disease the muscles may occasionally show a remarkable loss of tone. The early age of onset, the absence of all bony deformity, and the correct feeding adopted in this case all seem to exclude rickets as a possible cause. It may be that some of the cases described as the "acrobatic type of rickets" are examples of this disease.

The main feature of this case seems to be a loss of muscular tone, possibly due to a defect in the sensory mechanism in the muscles, and it seems to fall in the group of cases of congenital muscular atony first described by Oppenheim.

A CONTRIBUTION TO THE STUDY OF APRAXIA
WITH A REVIEW OF THE LITERATURE.

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Introduction.

The condition which has come to be known as apraxia or dyspraxia, or the inability of an individual who has neither motor nor sensory paralysis, nor ataxia, to perform certain familiar purposive movements, is by no means a new discovery. A cursory glance over not a few more or less old clinical descriptions of cases of aphasia will reveal instances of this form of disturbance of cerebral function, where phenomena undoubtedly of an apraxic nature are mentioned without any specific

term being applied to them. The more critical analysis, within recent years, of the symptom-complex of aphasia has led to wider recognition of the frequency and deeper appreciation of the significance of certain changes in the higher realms of cerebral function, and with this appreciation has arisen the necessity for the employment of new expressions to serve for these changes. We do not find the terms agnosia, asymboly, or apraxia in common use until we come within measurable distance of the present epoch of neurological activity. By agnosia is meant failure of intellectual recognition where there is integrity of primary identification; that is, where there is no impairment of simple perception. Thus, in the field of vision, if I see an object but fail to recognize it, I am suffering from a form of visual agnosia, or mind-blindness. If I hear a familiar sound, but fail to recognize it, I am suffering from a degree of auditory agnosia, or mind-deafness. If I feel an object in my hand, but am unable to recognize it by touch, my condition is one of tactile agnosia, frequently, but erroneously, called astereognosis. Similarly, we may be unable to recognize objects presented to us by other sense avenues; we may fail to recognize a familar smell or a familiar taste, though we taste and smell readily enough. Apraxia in its widest sense is, in a general way, at once a disturbance of perception and a disturbance of volition, or, rather, it may be the outcome of a disturbance of perception, or of volition, or of both. The defect may be psychosensory, or intrapsychical, or psychomotor in origin; hence the intimate relation of apraxia to the various forms of agnosia. If I cannot recognize an object presented to me, clearly I shall be unable to indicate its use; if a patient is handed a pencil and fails to perceive it is an instrument for writing, he may when told to use it put it in his mouth as though it were a cigar. In this instance there is obviously a psychosensory defect, and the ensuing apraxia is of a sensory type; it is apraxia of sensory origin, consecutive to visual agnosia. But, inasmuch as he believes the pencil is a cigar, the patient employs it correctly *quâ* cigar; in other words, the apraxia is not of a motor type. Should he recognize the pencil—and indeed he may say it is a pencil, and say further that it is used for writing—but when asked to use it, should he fumble with it in endlessly futile ways, he is exhibiting motor apraxia. These are very simple forms of apraxia, but one meets with still simpler instances. A hemiplegic patient may be unable to protrude his tongue when requested to do so, but that there is no paralysis is patent when he unconsciously licks his lips with that organ. The motor aphasic, in a sense, is affected with apraxia of his speech musculature. On the other

hand, apraxia may become highly complex as the result of special psychical defects or of a general mental deterioration; we shall see instances of this again. Sometimes the apraxic patient cannot make a given movement or series of movements unless he has the object in his hand with which the movements are associated—thus he cannot initiate the movement of counting out money; but put six pennies into his hand and he will count them out forthwith.

It is apparent that apraxia of sensory or motor or mixed type may occur in very varying conditions. Its association with different forms of aphasia is, of course, not infrequent, and the analogies between the two furnish an instructive subject for discussion. Apraxia is common in those forms of mental alteration which are the outcome of cerebral vascular degeneration; it is found in certain cases of intracranial tumour. It is seen in post-epileptic confusional states, also in the dementia of alcoholism and other toxic conditions. It may be unilateral or bilateral, transient or persistent, partial or complete. In making a diagnosis of apraxia the possible existence and influence of hysteria, of central or peripheral ataxia, of gross motor or sensory impairment, must be considered and excluded.

Our knowledge of apraxia is of relatively recent date; from the German school in particular have come many noteworthy contributions to the study of the subject, and the theoretical considerations with which Continental observers have enriched it have been the natural sequence of many painstaking clinical examinations of patients where apraxic phenomena have been discovered. It is of significance in this connection that Liepmann's classic case of apraxia, which will remain a monument of clinical insight and examinational ingenuity, was at one stage considered by superficial observers to concern so hopeless a lunatic as to promise little in instructiveness; yet it has come to be regarded as a model for future workers in this field.

In view of the desirability of a clear understanding as to the import of certain terms, and in face of the still existing discord in the interpretation of facts, a historical retrospect may not be devoid of value.

Historical.

There can be no doubt that one of the first to observe the phenomena with which we are dealing, and to give them a special name, was Hughlings Jackson, although (with the solitary exceptions of Pick [68] and Lépine [36]) none of the Continental writers alludes to

the fact. In a footnote on the first page of his "Studien" Pick remarks: "Es erscheint mir als ein Akt historischer Gerechtigkeit, auf die nur von Lépine beachtete Tatsache hinzuweisen, dass Hughlings Jackson wohl als einer der ersten die Störung klinisch erkannt hat; in einem zeitlich von mir nicht genauer zu fixierenden Aufsatze, der aber gewiss in die Siebzigerjahre zurückreicht, betitelt 'Case of Large Cerebral Tumour without Optic Neuritis, and with Left Hemiplegia and Imperception,' beschreibt J. unter der letzteren Bezeichnung die als Asymbolie oder Agnosie bezeichnete Störung." The patient referred to in this paper was seen in 1875, and the following passages may be quoted from the article [27] :—

"The first symptoms were those of what I call Imperception. She often did not know objects, persons, and places. . . . Now and then she would do odd things; she would put sugar in the tea two or three times over; she made mistakes in dressing herself; put her things on wrong side before, and did little things of that kind. . . . Imperception is a defect as special as aphasia. The case did not correspond, however, to loss of speech, but to defect of speech. There was partial imperception."

Failure to recognize objects (instances are given) in this case clearly points to a degree of visual agnosia, or mind-blindness, which is closely allied to sensory (agnostic) apraxia. The fact that the patient made mistakes in dressing herself is of interest; it is a defect to which I shall refer in a subsequent case.

But earlier still, in 1866, we find the following significant passages in a paper by Dr. Jackson, entitled "Remarks on those Cases of Disease of the Nervous System in which Defect of Expression is the most striking Symptom" [25] :—

"In some cases of defect of speech the patient seems to have lost much of his power to do anything he is told to do, even with those muscles that are not paralysed. Thus a patient will be unable to put out his tongue when we ask him, although he will use it well in semi-involuntary actions—for example, eating and swallowing. He will not make the particular grimace he is told to do, even when we make one for him to imitate. There is power in his muscles and in the centres for coördination of muscular groups, but he—the whole man, or the 'will'—cannot set them agoing. Such a patient may do a thing well at one time and not at another. In a few cases patients do not do things so simple as moving the hand (*i.e.*, the non-paralysed hand) when they are told. . . .

"One of my patients in the London Hospital had power only to say 'yes' and 'no.' . . . He had lost power to execute, not all movements, but those movements which are most artificial. . . .

"A few months ago a patient came under my care who could only say 'Pooh! pooh!' and an examination of his eyes was altogether impracticable. He made efforts, but he never did what I told him, whether it was to look in a particular way or to keep his eyes still. Instead of opening them he would open his mouth, or screw up his face, or shut his eye, and could not be got to look in any particular direction, although he seemed on the alert to act, and was all the time doing something with his muscles. . . .

"A speechless patient who cannot put out his tongue when told will sometimes actually put his fingers in his mouth as if to help to get it out; and yet not unfrequently, when we are tired of urging him, he will lick his lips with it. . . ."

One could not desire more apt clinical illustrations of pure motor apraxia than those thus figured by Dr. Jackson more than forty years ago.

In another paper (1878), entitled "Remarks on Non-protrusion of the Tongue in some cases of Aphasia" [28], we find the subjoined sentences:—

"The non-protrusion of the tongue is a thing of great scientific interest; considered along with some other symptoms of aphasia, it gives us a clue to the physiology of the whole of aphasia. . . .

"Some people are unable to draw in their breath deeply when told to do so during stethoscopic examination; we have to tell them to cough. It is next to impossible to get some patients to frown, as in suspected one-sided facial paralysis, even if we make a frown for them to imitate. . . .

"I have seen a patient who usually sat up in his room, whose face looked intelligent, who was cheerful and merry, and who seemed to understand all I said to him, but who could not put out his tongue when he tried. His daughter remarked that he could put the tongue out, as she expressed it, by accident, and added, as an illustration of her meaning, that when anyone was leaving him he could say 'good-bye,' but that he could neither put out his tongue nor say 'good-bye' if he tried. She further remarked that the patient would sometimes swear, but he could not repeat the word when he tried. She asked him to utter the explosive sound when I was there, saying it herself for him to imitate. He laughed, and shook his head. . . .

"All the above superficially different phenomena are fundamentally alike; they all show reduction to a more automatic condition."

It is abundantly clear from these extracts that Dr. Jackson not only recognized the importance and appreciated the significance of the condition known to-day as apraxia, but also advanced a theory of its causation, and when we remember that he observed and drew attention to the facts as long ago as 1866, we realize to what a remarkable extent he was ahead of his time.

Other early instances may be referred to. Von Monakow [56] mentions the case of a player on the clarionet who became aphasic, and thereafter was unable to put his lips into the position for blowing the instrument unless he actually had the mouthpiece in his mouth. Another motor aphasic was unable to blow into the air, though he could blow away ashes or dust. Bernheim [4] observed a characteristic case in 1883, where the failure of the patient to use objects correctly was noted and described as "une cécité psychique des choses." Griesinger [18] remarked how frequently an aphasic is unable to put his hand on a particular part of his body on request, and will touch his nose instead of his ear, &c. He regarded the mistake as due to confusion or perversion of movement, whereas Kussmaul [34], observing similar errors, thought they were due solely to confusion of words. Wernicke [82] had occasion, in 1884, to observe a patient without aphasia, but with loss of cutaneous sensation, who could not perform certain movements with his right hand if his eyes were shut. This uselessness of the arm was attributed to a loss of touch images; the failure to carry out more complicated acts with eyes closed was thought to follow from a loss of the corresponding ideas of movement.

In 1882 Westphal [83] published a carefully observed case, in which a patient who had considerable loss of the sense of position and of passive movement in the right upper extremity also exhibited a peculiar clumsiness in making use of it, even with his eyes open. Westphal considered the condition to be more than mere ataxia, and attributed it to a loss of kinæsthetic memories. In this way it may be likened to the *Seelenlähmung* of Nothnagel, to which we shall refer immediately.

Finkelnburg [14] was the first to employ the term "asymboly." Aphasia signifies inability to understand and to use certain conventional signs, viz., speech signs, and Finkelnburg noticed that many aphasics had lost other conventional signs; one of his patients could no longer understand the meaning of the symbols in the Roman Catholic Church service or of various business and political forms and signs. For all

types of defect of sign-recognition he used the term asymboly. But under this conception rather too much was gathered when he made it include cases of failure to recognize places and persons, *i.e.*, where not conventional signs, but the images of objects were concerned. Wernicke adopted this latter view of asymboly, and elaborated it to mean the loss of the memory pictures for an object. Thus patients with asymboly, in Wernicke's sense, can see, and hear, and feel, but impressions so gained are strange, and therefore useless, since they cannot recognize objects again by these means. They consequently show a lack of initiative; they cannot turn new sense impressions to account, which is the mainspring of action.

But the meaning of "conventional sign" attached to the word symbol prevented the general acceptance of asymboly in Wernicke's sense. Freud [16] suggested the word "agnosia" for defect in object recognition. Kussmaul, Starr and Pick [63] were the first to use the word "apraxia," but not in the present-day sense. Allen Starr [75] published a paper in 1888 on the varieties of apraxia and aphasia, in which the following definition is given: "It is found that each or all of the sensory organs, when called into play, may fail to arouse an intelligent perception of the object exciting them. For this general symptom of inability to recognize the use or import of an object the term apraxia is employed." And again: "To test for apraxia it is only necessary to present various objects to a person in various ways and notice whether he gives evidence of recognition." He quotes nine cases drawn from the previous literature, in all of which "power to recognize objects seen was lost." It is perfectly clear from Starr's account that his apraxia is nothing else than a limited visual agnosia, as we should call it to-day. Kussmaul used the word in more or less the same way. Laquer (1888) [35] said of an apraxic patient: "Es war ihr das Verständniss für den Gebrauch der notwendigsten Dinge verloren gegangen." The instances of this apraxia that he records show that the condition was really an agnosia, or imperception in Jackson's sense. Meynert [55] alone adhered to the opinions of Wernicke, and supported his contention in the following way: In various cortical centres there is for one and the same object a symbol, a sign by which it can be recognized. The loss of the sign of the object is asymboly. On the motor side the use of the object is associated with this sign of recognition, so that asymboly reveals itself in the patient's inability to make use of the object. A lesion in the central convolutions which hinders the awakening of the innervation memories (kinæsthetic images) of movements of the

upper extremity will cause motor asymboly. Meynert's sensory asymboly corresponds to Wernicke's asymboly, Freud's agnosia, and the apraxia of others, while his motor asymboly is similar to Nothnagel's *Seelenlähmung* (see below), but is not, however, identical with the apraxia or motor apraxia that Liepmann, as we shall see directly, has so thoroughly investigated and established.

Heilbronner [21] used the term asymboly in the sense of sensory asymboly or agnosia. At a congress in Breslau in 1894 Bonhoeffer [6] showed a patient whose state he described as one of mind-blindness with asymboly; in addition to complete sensory asymboly, the patient exhibited an extraordinary helplessness in carrying out purposive movements, many of which were curiously distorted or perverted. In this instance there was motor apraxia, although the reporter does not employ the term. At the same congress Heilbronner [20] demonstrated a case of asymboly, as he called it, yet no mind-blindness, no sensory defect of any kind, existed. His patient gave the impression of being able to perform any movement-complex, but he always became confused in its performance. As there was no motor defect to cause a motor asymboly (in Heilbronner's sense) the author described the condition as "conduction asymboly" (*Leitungsasymbolie*). We shall explain Heilbronner's views at a later stage. One reason why Meynert's motor asymboly is unsatisfactory is that the clinical case on which he based his views was an unfortunately complicated one, as the patient suffered from a degree of mind-blindness, of motor paralysis, and of ataxia. These are three causes of impaired use of a limb which have nothing to do with motor asymboly. Meynert thought the condition of his patient was intimately allied to what Kussmaul had called apraxia, but a reference to that author shows that he considered failure to recognize objects as the fundamental element in apraxia, *i.e.*, his apraxia and *sensory* asymboly are more or less analogous.

Closely connected with the conception of apraxia is the "mind-palsy" (*Seelenlähmung*) of Nothnagel [62]. Following on lesions, in the parietal lobes, of the cortical areas for motor memory pictures, the patient's arm under certain conditions, such as when the eyes are shut, became useless. He could not innervate it adequately by reason of his loss of the kinæsthetic images of the range and form of individual movements. This mind-palsy is a more limited disturbance of function than apraxia, for the apraxic patient cannot use his arm properly though he has the help both of eye and ear. In Bleuler's [5] case the patient could perform some movements with his eyes open which were impossible if he closed the latter; similarly in cases described by Bruns [9] and by

Anton [3]. Evidently we have here to do with an impairment of motility, a real palsy. Voluntary movements are diminished; in apraxia they are perverted. It may be noted, moreover, that Bruns [9] (and Bleuler, too) used the term *Seelenlähmung* to indicate cases where there was almost complete uselessness, or even immobility, of the limb, with no actual paralysis and no perversion of movement. These fall into the category rather of akinesia, therefore, than of apraxia.

A great impetus was given to the study of the subject by the publication, in 1900, of Liepmann's [40] case of unilateral apraxia. As has been already noticed, the term apraxia was at first proposed to signify the misuse of objects from failure to recognize them, though Freud had seen the advantage of calling this condition agnosia. To Liepmann must be assigned the credit of having elaborated the conception of a true motor apraxia, a defect in the use of objects, though they are perfectly recognized. He warmly advocated the restriction of the word apraxia to this form alone, considering agnosia preferable to sensory apraxia. If we are to regard every objective perversion of action, from whatever preceding cause, as apraxia, then the conception becomes unwieldy. We may call the blind apraxic because of their uncertainty, their running against objects; the word-deaf must be apraxic; the lunatic who mistakes his friend for an enemy and shoots him is apraxic. Thus conceived—for we must remember that we can gauge the psychical processes of the individual chiefly, if not entirely, by their motor exteriorization—the term becomes valueless. From the minute analysis of his own patient, Liepmann ventured to define motor apraxia as "incapacity for subjectively purposive movements of the limbs, with conservation of the power of movement." The apraxic subject is handed a cigar and asked to indicate its use; he knows it is a cigar, and the idea in his mind, his purpose, is to smoke it; he cannot translate this subjective purpose into action, and fumbles with the cigar; he is unable to perform subjectively purposive (*zweckgemäss*) movements. The agnosic patient, on the other hand, is given a toothbrush, and asked to show how it is used; he thinks it is a cigar, and accordingly the idea in his mind is to smoke it, which he proceeds to do; his movements, therefore, *are* subjectively purposive. If the idea in the patient's mind be absurd or grotesque, and if it be translated into action, the movements are not objectively purposive (*zweckmässig*)—in fact, they may appear objectively purposeless—though they may be, and are, subjectively purposive (*zweckgemäss*).

Liepmann [43] devised a fresh classification of the disturbances of cerebral function which interest us here as follows:—

(1) *Agnosia*—subdivided into :—

(*a*) Mind-blindness.

(*b*) Mind-deafness.

(*c*) Tactile agnosia (*Seelentastlosigkeit, Tastlähmung*).

(*d*) Gustatory agnosia (*Seelengeschmacklosigkeit*).

(*e*) Olfactory agnosia (*Seelengeruchlosigkeit*).

Word-blindness (and it, in turn, has various subdivisions) is a partial mind-blindness. Any of these may be met with separately. A combination, in varying degree, may produce a result equivalent to Wernicke's asymboly, Meynert's sensory asymboly, sensory apraxia (a term to be avoided), Jackson's imperception.

(2) *Ideational apraxia.*—If, as a sequel of want of attention, or imperfection of memory, or deficient retentiveness, or for other reasons, the separation of the main idea of action into its component ideas of action is impaired, then the movement that results is conditioned by the erroneous component ideas, and ideational apraxia ensues. Ideational apraxia is linked more to agnosia than to motor apraxia, and is nearly always present with the former. In this type the faulty ideational, intrapsychical process is alone responsible for the apraxia.

(3) *Motor apraxia.*—If there is an interruption between the main idea of action as a whole and its carrying into effect as a whole, *i.e.*, between the idea of the movement and the innervation of the movement (with which, according to Liepmann, is associated the kinæsthetic element in the idea), the outcome is motor apraxia.

At an International Congress for Psychiatry and Neurology, held at Amsterdam in 1907, Liepmann [50] approached the subject from a rather different standpoint, and suggested the following four varieties of defective motility in a limb :—

(1) The muscles of a limb may not be paralysed, but the patient may be able to make very little voluntary use of them (*Willenslähmung ; Seelenlähmung* in Bruns' sense).

(2) The limb may not be paralysed, but the patient may have lost certain combinations of movements which he formerly had acquired ; delicate movements may be impossible, and the remaining movements awkward and unskilled. This variety is akin to cerebral ataxia in the strict sense, depends on the loss of kinæsthetic images of limb movements, and may be called "limb-kinæsthetic apraxia" (*gliedkinetische Apraxie*). This is identical with Meynert's motor asymboly, Nothnagel's *Seelenlähmung*, and, as we shall see, Heilbronner's cortical apraxia. In that form of "mind-palsy" where the patient is unable to use a limb unless the eyes are open there is loss not merely of kinæsthetic images,

but also of kinæsthetic impressions, so that he has to depend on his visual memories of movement.

(3) Limb-kinæsthetic memories are preserved, but isolated from other association fields, or not in sufficient touch with them. Ideational processes and kinæsthetic memories are severed. This is motor apraxia *par excellence*, or ideo-kinæsthetic apraxia.

(4) Limb-kinæsthetic memories are normal, and in normal association with other areas in which arises the mental "sketch" or "draft" of an act, but this ideational plan is itself defective, and the subsequent movement betrays the fact. This is ideational apraxia, identical with Pick's ideomotor apraxia.

We owe to Arnold Pick, of Prague, various noteworthy contributions to the study of apraxia. As long ago as 1892 he applied his analytical ingenuity to the problems of aphasia, and advances that have been made are in no little measure due to his labours, the value of which has always been enhanced by his ready appreciation of the work of others and his quickness to combine it with his own in increasing the sum of human knowledge. Pick's original definition of apraxia is couched in the following terms [63]: "Mit dem Ausdruck Apraxie bezeichnet man den nicht durch allgemeine Herabsetzung der psychischen Functionen bedingten Verlust des Verständnisses für den Gebrauch der Dinge." As has already been hinted, and will now be seen, Pick looked at apraxia rather from the sensory side, but he was one of the first to demonstrate the possibility of the occurrence of apraxia apart from any loss of kinæsthetic or other sensory images and memories. The persistence of certain impressions may become a fertile source of error in the execution of complex movements; a patient may recognize an object and use it correctly, but be unable to prevent himself from repeating this act when a totally different object is presented to him. He may use a spoon properly, but repeat the action of feeding himself with the next thing he is shown, which may, for instance, be a corkscrew. This phenomenon, to which Neisser [59] gave the name of "perseveration" (*perseveratorische Reaktion*), this inertia or fixation of idea (*Festhaften, Haftenbleiben*), is curiously frequent in the determination of apraxia. Pick emphasized its importance, and gave the resulting defect the name of "pseudo-apraxia," and in later publications he has continued this usage. In his "Studien über motorische Apraxie" [68] (1905) many interesting facts are recorded and their interpretation discussed. Attention is devoted to the not uncommon occurrence of odd, inapposite movements (*vertrakte Bewegungen*) of face or other musculatures as an

accompaniment of apraxic phenomena.[1] They are not of the nature of ordinary associated movements, and are distinguished as parakinesia, or parakinetic movements. An excellent illustrative case, in which true apraxia also was present, has been reported by de Buck [11]. Pick also employs the term "parapraxia," by which is meant the condition where the patient has a normal idea of the intended act, but instead of accomplishing the desired movement he finds himself making an entirely unintended and wrong, though also purposive, movement (*Bewegungsverwechselung*). Pick has devoted some attention to this variety. We have already noted that Liepmann's ideational form is called by Pick ideomotor apraxia.

Since Liepmann's conscientious and illuminating work on the subject, various observers have materially aided in supplying further clinical, pathological, and theoretical data for consideration. The names of Kleist [31], Marcuse [54], Hartmann [19], von Monakow [57], Bonhoeffer [8], Herzog [24], Lewandowsky [39], Maas [53], Abraham [2], Stransky [76], Knapp [33], Nicolauer [60], and Heilbronner [22] may be mentioned. The last named in particular has enriched the study of apraxia with much original observation. He suggests the following classification:—

(1) Cortical apraxia (cortical motor asymboly).—This form is characterized by impairment of the specific functions (*Eigenleistungen*) of the sensomotorium and by the preponderance of parakinetic movements in the execution of any muscular act, or series of acts. It corresponds to Meynert's motor asymboly and Nothnagel's *Seelenlähmung*.

(2) Transcortical apraxia (transcortical motor asymboly).—In this variety the specific functions of the sensomotorium are intact, while voluntary movement-complexes are defective, and in their place we find the inapposite movements already referred to as parakinesis. To these has been applied the term "paramimia" (Liepmann). Parapraxic movements (*Bewegungsverwechselungen*) also occur. Liepmann's case belongs to this category.

(3) Conduction apraxia (*Leitungsapraxie*).—Here we find highly variable defects and perversions of acquired familiar movements and acts, chiefly through the tendency to inertia of idea; there is practically no parakinesis, and the functions of the sensomotorium are normal. Most of the hitherto recorded cases will come under this last group.

(4) Agnosia, with its various subdivisions as previously described. Many errors in movement are secondary to some form of agnosia.

[1] Dupré [12] mentions the occurrence of these movements in general paralysis, and, without referring to apraxia at all, bestows on them the unnecessary name of "parectropia."

Types (1) and (2) may be unilateral, and may be combined. Types (2) and (3) are often closely allied, while type (3) is usually coexistent with some defect of type (4).

It may appear from this sketch of the subject that unanimity of opinion is still unattained, and that the differences in detail are too great to be surmounted. We see, of course, how the meaning of the word apraxia has changed, but in view of its etymology we can have no hesitation in according our support to the contention of Liepmann that the word should be reserved for a defect on the motor side of the sensori-psycho-motor arc, and on the motor side alone. No good purpose can be served by the adoption of the phrase sensory apraxia, when agnosia is shorter and more accurate, unless the statement is specifically made that what is meant is apraxia of sensory (*i.e.*, of agnostic) origin. For this reason I propose the term, and shall hereinafter speak of, "agnostic apraxia," *i.e.*, apraxia secondary to agnosia.

Further, we may remark that exception is taken by Liepmann [47] to the use of the expression "parapraxia." It is to be observed that apraxia and paralysis are not identical; the person who cannot make purposive movements with his arm because it is paralysed is not apraxic but akinetic. Now, the parapraxic patient makes one movement where he obviously intends to make another; he waves his finger in the air when he means to put it on his nose; he has failed to execute this particular subjectively purposive movement; but according to the definition the apraxic patient, too, cannot make subjectively purposive movements; hence apraxia and parapraxia are really the same. We can scarcely say, therefore, that parapraxia and apraxia are related as are paraphasia and aphasia. But this question may be left aside for the present.

In spite of differences and hiatuses, however, from the material now available certain facts stand out which warrant us in attempting something more than a merely tentative definition and classification, and once this stage is reached in the prosecution of any subject we know from the experience of other times and other topics that subsequent accumulation of clinical data will not confuse, but will serve to elucidate.

Definition and Classification.

Apraxia may briefly be defined as follows:—

Inability to perform certain subjectively purposive movements or movement-complexes, with conservation of motility, of sensation, and of coördination.

Imperfect motility and inaccuracy of movement may be of manifold origin. The place which apraxia takes in the series may be profitably demonstrated if we set down in order, from the afferent to the efferent side of the cortex, the various defects of cerebral function that may occur to impair movement. In this process we shall begin with sensory paralysis, and pass over the sensori-psycho-motor arc to motor paralysis.

(1) *Cortical blindness, cortical deafness, cortical sensory paralysis:* Loss of visual, auditory, and cutaneous ingoing sensory impressions.

(2) *Cerebral ataxia* (*Rindenataxie*): Loss of afferent kinæsthetic impressions, resulting in erroneous estimation of range, power, &c., of movement.

(3) *Mind-palsy* (*Seelenlähmung*): Incapacity for movement from loss of kinæsthetic images and memories for complex movements.

(4) *Agnosia, mind-blindness, mind-deafness, &c.:* Conservation of sensation, but failure of recognition; loss of sensory memory pictures; interruption of connections between sensation and memory.

(5) *Ideational agnosia:* Loss of the spatial associations and interconnections that build up the idea of an object from its component ideas.

(6) *Ideational apraxia:* Defective synthesis of the ideational components of a movement-complex; defective psychical "sketch" of movements or acts.

(7) *Motor apraxia:* Intactness of the cortico-muscular apparatus, but inability to translate a normally produced idea of a movement into the corresponding movement-form.

(8) *Motor paresis or paralysis.*

Perseveration as a cause of disturbance of action is best included under (6).

Clinical.

The materials for the scientific study of apraxia are increasing; already the facts are almost more than can be easily assimilated, but, on the other hand, various hypotheses have been advanced which have not as yet received adequate support, and workers in this field must continue to gather and sift ere finality can be reached. I do not propose to do more than illustrate the different types of apraxia by cases which are unequivocal in their bearing, and which are sufficiently clear instances of the particular variety under discussion. I have myself observed and examined not a few patients who present the phenomena that concern us here, and I should like to take this opportunity of

acknowledging my great indebtedness to various members of the National Hospital staff for permission to refer to cases under their care. In addition, my thanks are due to Dr. W. H. B. Stoddart, of Bethlem Royal Hospital, for clinical material generously afforded me, and for his kindness in allowing me to examine patients independently.

(1) *Instances of Motor Apraxia.*

It has already been remarked that many patients with motor aphasia are unable to make certain movements though the muscles concerned are not paralysed. Such patients often fail to put out the tongue on request. One patient[1] with severe motor aphasia was urged in vain to protrude her tongue, but on being told to put a stamp on a letter addressed to her husband she put out her tongue to lick the stamp. Frequently these patients are unable to cough voluntarily, are unable to take a deep breath, are unable to sigh when asked to do so. I have observed that not uncommonly they cannot make the movement of swallowing, though they have not the slightest dysphagia when they are actually eating. An aphasic patient[2] was unable to sniff voluntarily, but when he was offered a flower he sniffed it at once. These are examples of bilateral apraxia, which is common in the muscles of the head, neck, face, and trunk. One of Lewandowsky's [38] patients, with cerebral diplegia, was unable to close the eyes voluntarily, though the lids followed the eyes downwards and were closed during sleep. Some hemiplegic patients seem to be unable to close the eyes properly on request. Others cannot make a given grimace.

Unilateral apraxia in the non-paralysed arm is not infrequent in cases of hemiplegia with or without motor aphasia; that is, left-sided apraxia occurs in a left hemisphere lesion. The significance of this we shall see again. The following is an abridged note of the examination of such a case[3] (the symbol + means that the patient's response was correct):—

Shut your eyes	+
Put out your tongue	+, but shut eyes at same time.
Show your teeth	+
Put your left hand on your head ...	Put left hand on chin.
Look astonished	Put left hand on chin.

[1] A. N., under Dr. Beevor.
[2] J. W., under Dr. Ormerod.
[3] W. P., under Dr. Ferrier.

Smile	Made hissing noise through teeth.
Look angry	More or less correct.
Put your left hand on your right ear ...	Put left hand at once into left eye.
Put your left forefinger on your nose ...	Caught hold of nose with finger and thumb of left hand.
Cough	Took a deep inspiration and blew through teeth several times.
Take a deep breath	Made a hissing noise through teeth twice.
Close your left hand	+
Open your left hand	+
Make movement of cutting with scissors	Indefinite movements of left forefinger and thumb.
Make movement of striking a match ...	Stuck forefinger and thumb vertically on to bed.
Make movement of counting pennies out of your hand	Touched thumb and tip of each finger in turn.
Turn the handle of a barrel-organ ...	+

With actual objects in his left hand the patient succeeded a little better, but the motor apraxia was none the less obvious.

Given a buttonhook	Fumbled with the object aimlessly.
(Was shown how to use a buttonhook, and then)	
Given a papercutter	Made the movement of buttoning.
Given a pencil	Used correctly.
Given a brush	+
Given a comb	+
Given an anchor	Combed his hair with it, then moved it to and fro on the bed-clothes and said "Whoa!"

This brief excerpt contains highly characteristic examples of bilateral and unilateral motor apraxia, with perseveration, inapposite movements (*vertrakte Bewegungen*), and so-called parapraxia. Be it observed that there was neither word-deafness nor object- and mind-blindness, *i.e.*, the apraxia was not of agnostic origin. When asked, the patient indicated clearly enough that he knew what the objects were for; but when he came to translate his ideas into action he made either an unintelligible or else an entirely wrong movement (so-called parapraxia). The

phenomenon of perseveration is well exemplified, and suggests a somewhat wider impairment of cerebral function.

A patient whom I saw at Bethlem was handed a cigarette-holder, consisting of quill and amber piece, and a cigarette. He recognized the objects, and said they were for smoking, but when he was asked to put them together, he tried to put the cigarette into the quill, then into the wrong end of the amber piece, and finally, after further efforts, he laid the objects down. Pick [68] tells of a patient who was given a five-crown piece into his right hand. The sleeve of his shirt was rather long, and came over his wrist so as to hide the money. He made the most futile attempts to bring out the coin, ignoring his other hand, and then, with a long-drawn sigh, put the object aside. Another case was given a candle and a match-box: she took out a match, made rubbing movements with it in the air above the candle, then reinserted it in the box. On being urged to light the candle, she took a lighted match which was offered her, held it near the wick of the candle, then blew it out.

Liepmann's [40] [47] case of unilateral motor apraxia has become celebrated, and justly so, for the completeness and instructiveness of the examination. His patient was a man aged 48, who contracted syphilis twenty years before, and showed indications of widespread arterial degeneration. He had a series of attacks which left him in a state of what was characterized as "almost absolute imbecility." The diagnosis was apoplexy, mixed aphasia, and dementia, and he was sent to an asylum. When he came under the care of Liepmann there was no paralysis, except slight weakness of the left side of the face. (At a later stage the paralysis extended considerably—see below.) Hemianopia was absent, but there was some diminution of the knowledge of the sense of position and of passive movement on the right side of the body, diminution of sensibility to pain, and impairment of the faculty of recognizing objects by touch alone. He suffered also from motor aphasia, but there was no trace of word-deafness. It was soon found that he had bilateral motor apraxia for face and neck and head movements, and unilateral apraxia of the right arm and right leg. Asked to put his right forefinger on his nose, he said "yes," and with his stretched forefinger executed wide circling movements in the air. He made the correct movement at once with his left hand. Asked to close his right hand into a fist, he performed various absurd movements of his arm and body, but attained the required goal at once with his left hand. When asked to give the examiner a certain object

with his right hand, he frequently picked up the wrong thing, and, still holding it in his hand, used the left to take up the required object and present it to the physician. He was desired to brush the examiner's coat: accordingly, he took the lower corner of it correctly with his left hand and held it out, while with his right he picked up the brush, but made rhythmical movements with the latter in the air above his right ear. He was asked to pour water out of a carafe into a tumbler: his left hand grasped the handle of the carafe to pour out the water, but his right hand seized the empty glass and brought it at the same time in the direction of his mouth. At a telephone he took the left receiver with his left hand and applied it to his left ear; with his right hand he turned the handle first one way and then another, then took the right hand receiver and put it on his forehead, making nodding and puffing movements the while; then he held the receiver before him and gazed into it, finally carrying it to his mouth and then behind his ear. The movements of the right hand in this last example may be cited to illustrate so-called parapraxia.

Enough has been quoted to exemplify the inability of the patient with motor apraxia, in spite of the absence of any perceptual defect, to translate his ideas into the corresponding action; de Buck's [11] patient was asked to lift her right arm, but after crossing it over her body, putting her hand in her left axilla, and making various energetic but hopeless efforts, she said plaintively, "Je comprends bien ce que vous voulez, mais je ne parviens pas à le faire," and there lies the whole situation in a nutshell.

(2) *Instances of Ideational (Ideomotor) Apraxia.*

One or two of the examples that have already been given illustrate rather more than a purely motor or psychomotor defect. Without entering on detailed analyses of each I shall now give a few instances of the apraxia that results from interruption of intrapsychical function.

One of Pick's [68] patients was handed a toothbrush, which he recognized, but when asked to use it he began to brush his beard with it clumsily. This is an excellent instance of the so-called "associative apraxia" of Bonhoeffer [8]. Evidently the concepts "toothbrush" and "beard brush" were confused, with a consequent confusion of movement. The patient "went off the rails" (*Entgleisung*) in the ideational part of the act. On another occasion a pistol was offered him, which he said was a revolver; to show how to shoot he grasped the barrel, blinked,

and put the muzzle against his right eye. Liepmann [43] takes this example to indicate the same associative apraxia, inasmuch as the object had not called up the special idea of a pistol, but the general one of a firearm (which suggests some slight agnosia and shows the close relation of agnosia to this form of apraxia); and the idea of a gun controlled the subsequent movement. When the patient was supplied with a cigar and a matchbox he opened the latter, stuck the cigar in, and tried to shut the box, apparently as though it were a cigar cutter. Then taking the cigar out he rubbed it on the side of the box as though to light a match. In this movement-complex, the components of the main idea of action, viz., to light a cigar, neither followed in the right order nor were directed to the proper objects—a fine illustration of ideational apraxia. On yet one other occasion, when all the necessaries for smoking were laid before him, he took the matchbox and, putting it between his teeth, tried to smoke it. Here the ideational components of the complex are omitted. No sooner is the action begun than the movement that should come last is carried out. This is a good example of what is called the *Kurzschluss-Reaktion* (short-circuit reaction).

In another case [68] the patient recognized a shoebrush, and picked it up to brush his boots, but rubbed it over an excoriated area of his skin instead. A sensory impression from the skin interrupted the "draft" of the action and diverted the patient's "intention."

In this connection I may refer to a patient with arterio-sclerosis at Bethlem. I invited him to make the movements of counting out money with his right hand, which he effected very badly. Accordingly I made the movements myself for him to imitate, and he began to do them correctly enough; to aid him, as I thought, I told him to count into my hand, and put it out for him to count the (imaginary) money into, when he at once grasped it and shook hands with a smile! One may say here, too, that the ideational plan of action was interrupted by impressions from other sensory centres, and the incident is a further illustration of the influence of perceptual defects in the production of ideational apraxia. It is interesting, also, as showing the persistence of those movements which have the greatest number of associations. The associations which the sight of my hand awakened were more potent for the movement of shaking hands than for the movement of counting out money.

Where a greater degree of cortical functional disintegration exists, as in many cases of dementia, from whatever cause, apraxic phenomena may appear in increased complexity. One reason for this is the

frequent concurrent development of agnosia in some or other form, and this agnosia may be profound. Mental troubles of a general nature, such as amnesia, inattention, incapacity for retaining impressions, lack of initiative, militate against eupraxia, apart from impairment of the specific sensori-psycho-motor paths. Marcuse [54] has described apraxia in senile dementia; Abraham [1] and Lewandowsky [37] in general paralysis; Stransky [76] in senile cerebral atrophy; Bonhoeffer [7] in the delirium of alcoholism; Pick [66] in post-epileptic stuporose conditions, &c. I shall have occasion to refer to some of these cases immediately apropos of the determining factors in the production of apraxia. Because a patient is insane, demented, delirious, any apraxia which he may show is none the less apraxia; it is none the less deserving of study. The more we can reduce psychical disturbance to its component elements, and the better we can estimate the action of known pathological processes, the less elusive and mysterious will that disturbance become.

Determining Factors in the Production of Apraxia.

(1) *Agnosia.*

For various reasons it is not desirable to say much in regard to the position of agnosia as a factor in the production of apraxia. To enter into the question at all adequately would prolong this paper unduly. The different forms of agnosia have already been sketched, and a mere glance at their variety will suffice to render obvious the manifold possibilities of agnostic apraxia. There are many ways in which recognition of an object may be at fault. The idea of, say, a tree is a complex of simple ideas (twigs, leaves, trunk, roots, &c.). Each of these is in itself complex, for we have, in the first place, the idea of the spatial form and relations of each part, and, secondly, a sum of qualitative subsidiary ideas, viz., visual, tactile, olfactory, &c., for each part. In the process of recognition of an object, the two series of partial ideas are linked together. Each idea of an object is a complex of component spatial ideas and of component tactile, visual, and other qualitative ideas. If there is any interruption, by pathological processes, between the qualitative (visual, tactile, &c.) elements in one or more of the component ideas that go to form the idea-complex, then we have a disturbance of recognition which is known as (sensory) agnosia. There are as many varieties of this disturbance as there are senses. Clinically we have preservation of primary sense perception, with inability to awaken

images through a particular sense; from any of the other senses the idea can be awakened. A patient may have visual agnosia, but not tactile agnosia. Meanwhile, the association of the spatial component ideas in the idea-complex is not interfered with. But a lesion may cause dissolution of the associations between the spatial component ideas of the complex idea; there is a defect in the building up of the idea from its constituent ideas which does not depend on the quality of the original sense impressions; *i.e.*, whether the object be seen, or felt, or heard, is a matter of indifference. This disturbance of recognition is ideational agnosia.

Now, this brief psychological sketch will help us to realize the complexity of the process of identification by any one of the senses, and the corresponding complexity of imperception. Mistakes on the sensory side are exteriorized into errors of movement, hence the multiplicity of apraxic phenomena of agnostic or perceptual origin. What has been said of ideas of objects is true of ideas of movement. The latter may be divided into the spatial components of each partial idea in the complete idea and the qualitative (visual, kinæsthetic, &c.) components of each partial idea. Ideational defects entail apraxia here also.

There are many instances of apraxia of agnostic derivation in the literature. As a matter of fact, much more attention has hitherto been devoted by observers (with the conspicuous exception of Liepmann) to the study of the psycho-sensory side than of the psycho-motor side of impaired mentation. Nearly all the early cases of apraxia were cases of agnostic apraxia, of which many examples might be given. A patient of Laquer's [35] used a comb instead of soap to wash her face with. She bit into the soap, but recognized it by its taste. Agnostic patients often take hold of objects in the wrong way. The reader will find instructive the apraxia of Pick's [64] patient, who laboured under the disadvantages of auditory agnosia, visual agnosia, partial tactile agnosia, olfactory agnosia, and gustatory agnosia.

One of the Bethlem patients already referred to exemplified a highly complex type of combined agnostic and ideational apraxia. I handed him a match—he was a great smoker—and asked him what it was. He said at once, "Oh, that's a pen." I agreed, and requested him to demonstrate its use. He replied, "Why, you clean your teeth with it," and, at the same time, he took it in his right hand and cleaned his finger-nails with it.

In this admirably suggestive incident the patient's visual agnosia was responsible for his saying that the match was a pen. In all probability

he meant a pen nib. So far, however, from using the match as a pen, he was deflected from that idea by the association of a pen nib with something pointed, so that a tooth-pick rose in idea before him; again association interrupted his ideational sketch, and at the same moment as he said "*teeth*" he carefully manicured his *nails*. It is another instance of associative apraxia.

(2) *Perseveration.*

A factor in the determination of apraxia, noteworthy both for its frequency and its compelling character, is perseveration. Perseveration, according to Pick [66], is the result of feeble associations. The individual is absorbed by one idea to the exclusion of others which the examination ought to awaken. Such perseveration is of ideational origin, but the question is a difficult one to answer whether it is due to abnormally long persistence of the first idea ("ideational inertia" is the term suggested by Dr. Stoddart) or to some hindrance in the presentation of subsequent ideas. Liepmann [43] has enlarged on the importance of recognizing perseveration of psycho-motor origin. A motor innervation which has already been carried into effect repeats itself whenever the patient endeavours or intends to make a different innervation. There is neither persistence of innervation nor spontaneous innervation, but a repetition of the already executed one when (and only when) he intends to make a new movement. Liepmann distinguishes this variety as "clonic perseveration."

Pick's "Studien" contains many examples. One of his patients blew out a candle, and then blew on all objects subsequently presented to him. There is often a characteristic perseveration in the parapraxia of motor aphasics and other hemiplegics on the non-paralysed side.

In the selection already made from the examination of the case W. P., there are instances of the same *Haftenbleiben*. He was given a small comb, which he used correctly, then a toy anchor was put into his hand, and he combed his hair with it as well. In the same way he repeated with a paper-cutter the movements of buttoning with a buttonhook.

To another[1] of the patients who has come under my own observation—a case of generalized cerebral arteriosclerosis—I handed a match, and asked him if he knew what it was; he said it was a match, and at once made the correct movement for striking it. I then gave him a

[1] S. C., under Dr. Risien Russell.

pencil; he said, "That's a piece of pencil," and when asked what it was for, he continued, "For writing, of course." "How do you use it?" "Oh, you strike it like this," he said, and repeated the identical movement he had made a minute before with the match.

Another patient[1] recognized a small magnifying glass which I gave him, and, saying, "That's a very pretty thing," put it to his eye correctly. He next received a Yale lock key, which he did not know. On being told what it was, and in spite of the fact that he repeated "key," when asked to use it he put it to his eye and said, "That's a very pretty thing."

Perseveration of speech and perseveration of writing are of much interest. A patient under the care of Abraham [1] who had been asked to put out his tongue was then told to write down something, when he at once wrote "tongue," and continued to do so in answer to other questions. One of the Bethlem patients, suffering from early arteriopathic dementia, was given a buttonhook, and said, "Oh yes, that's for boots." He made a poor attempt to indicate the method of using it, and was handed a knife. He looked at it a minute or two, then said, "That's for boots." He could not get any further with the object, so I gave him a matchbox, which he fumbled with rather helplessly, and when I opened it for him he said, "I think that's for boots."

It may be noted, in passing, how very different perseveration of speech is from the "recurring utterances" described by Hughlings Jackson, and from the verbigeration of certain forms of insanity.

(3) *Absence of Initiative.*

Connected with perseveration is another psychical defect of some significance, called, in Germany, *Willenlosigkeit;* we might coin a word "will-lessness," but "defect of volition" or "absence of initiative" is sufficiently accurate. Not infrequently apraxic patients exhibit a curious lack of spontaneity, an unwillingness or inability to do things for themselves, which is not without bearing on the development of apraxic phenomena. In one or two of the recorded cases this lack of initiative has been remarked, and Pick [68] has devoted some attention to it. One of his patients had a burnt match in his hand and seemed unable either to let it go or to throw it away. Liepmann's [40] patient complained that sometimes he could not relinquish his grasp of an object in his left hand. Pick's view is that there is momentary cessation

[1] At Bethlem.

of spontaneity, momentary "will-lessness." Liepmann thinks there there is persistence of innervation, a condition which he describes [43] as "tonic perseveration," as opposed to the "clonic perseveration" of the previous paragraph. Other instances may be cited with advantage. One of Bonhoeffer's [7] patients, who showed agnostic apraxia, associative apraxia, perseveration, &c., would allow his legs to rest wherever they were passively put by anyone. He rarely moved them voluntarily. Bonhoeffer uses the term pseudo-flexibilitas cerea for the condition, which is obviously distinct from true flexibilitas cerea. Absence of spontaneity is not infrequently associated with agnosia. The remark of Wernicke has already been quoted, that patients with asymboly cannot turn new sense-impressions to account, which is the mainspring of action. Rabus [71] agrees that such patients must appear stuporose, since the ideas which constitute their mental life are in great part gone, and impressions from without fail to elicit any response. Bonhoeffer [7] has noted the remarkable fact that patients in the delirium of alcoholism may, on request, move their hands and arms, put out the tongue, &c., but they will not stand up spontaneously, or turn about from one position to another, or draw their feet or legs up. A general paralytic under the care of Lewandowsky [37] showed extraordinary inability to do anything for himself: he could not sit up, rise from his seat, walk forwards or backwards, unless he was made to do so, when the movements were accomplished normally enough. In this patient's case there was a slight paresis of the left arm, yet with it only three movements were ever executed, viz., one to the back of the ear, one to the mouth, and one a rubbing movement of the hand on the head. One of Pick's [68] patients was asked to go to the table and eat something; he went forward and put his face into a milk-jug which was standing on the table, and remained so, almost motionless, for several minutes. The interpretation of these interesting facts, where action seems to come to a standstill, is, as already hinted, debatable. Pick inclines to the view that the idea which impels an act is lost with the commencement of the act, a form of ideational inertia. He quotes from James [30]: "A certain intensity of the consciousness is required for its impulsiveness to be effective in a complete degree. There is an inertia in all motor processes as in all other things. In certain individuals and at certain times (disease, fatigue), the inertia is unusually great, and we may then have ideas of action which produce no visible act." Of course, certain instances of this condition may be due to absolute lack of attention or to the fleeting character of afferent impressions (see also below).

There is a case[1] of left hemiplegia in the National Hospital at present which presents certain features of unusual interest for our subject. It is a case of mitral stenosis with an ordinary embolic lesion of considerable extent in the right cerebral hemisphere. The clinical picture is one of complete flaccid paralysis of the left arm and leg; the left face is also affected, but to a much less degree. On examining the patient one is at once struck with her immobility and lack of spontaneity. She rarely speaks unless spoken to; she still more rarely makes any voluntary movement of her non-paralysed right limbs. When requested, however, she can perform any movement with her right arm in an eupraxic way, and there is no agraphia. Her face is more or less "fixed" in an expression suggesting anxiety; her eyebrows are symmetrically elevated, and her eyes look straight in front of her. This expression never varies. She is quite incapable of making any grimace, of smiling, of laughing; when asked to try, her reply is "I can't." She is incapable of closing her eyes on request, or, rather, of sustaining the contraction, for she will close them momentarily, opening them again without the slightest pause. She is unable to look voluntarily to the right or the left, and it is only with difficulty that she can be tempted to gaze in either of these directions, by the stimulus of a sound or otherwise. Yet there is no paralysis of conjugate deviation at all. She can protrude her tongue, can show her teeth, bite, &c., well enough. Her voice, since the stroke, has been peculiarly monotonous and rather shrill: she is incapable of modulating it. There is a fixity of tone more or less in keeping with the fixity of her facial expression, but I have the authority of Sir Felix Semon for the statement that the larynx is normal. She is incapable of making the movements of swallowing, though with food in her mouth she swallows well, if slowly; she cannot cough, or sigh, or yawn voluntarily.

Here, then, is a left hemiplegic patient with bilateral apraxia of face and throat musculature for certain movements, and with pronounced defect of volition or of initiative. Such a case may be considered in two ways. There may be actual paralysis of certain movements. But, as has been indicated, there are in this case few, if any, movements that are really lost. On the other hand, there may be inability volitionally to awake or innervate certain movements or movement-complexes, and thus apraxia may be determined. The kinæsthetic ideas of these movements are intact, but the patient cannot voluntarily revive them. Such seems to be the case in this instance.

[1] A. P., under Dr. Risien Russell.

Those who have had occasion to study astereognostic patients must have been struck with the way in which they seem to have difficulty in handling the object properly, though there is no trace of motor paralysis.[1] That this deficient handling and turning to and fro of the object do not necessarily depend on loss of sensation—and therefore cannot be likened to the deficient motility of the apæsthetic limb—is clear from their occurrence where there is no discoverable diminution of cutaneous or even of deep sensation.

A patient[2] recently seen, from whose right superior parietal lobule a bullet was removed, exhibited astereognosis in the left hand for several days after the operation. No loss of cutaneous sensation existed, but there was occasional (not constant) erroneous estimation of passive movements of the fingers, particularly of flexor movements. When he was tested with Cattell's algometer no alteration in deep pressure pain was found. He betrayed no motor paralysis whatsoever, but when an object was put into his left hand, his eyes being closed, he grasped it firmly with his whole hand, and showed no spontaneity in fingering it or handling it. He never made any effort to manipulate it at all: even with eyes open there was little initiative in fingering it. One may very well question whether the astereognosis was not secondary to the akinesia of the hand and fingers, a "pseudo-astereognosis." It is possible that the condition was analogous to Nothnagel's *Seelenlähmung*, and due to failure of kinæsthetic memories and impressions, but the patient could on request make at least some normal movements with his left fingers and hand when his eyes were shut. One is rather inclined to class the case as a dyspraxia secondary to perseveration or absence of initiative—a volitional defect which may in some way be due to absence of certain normal afferent stimuli, and the local incidence and transitory nature are of great interest.

I have also seen a case[3] of right cerebral tumour with progressive left hemiplegia, where the patient is unable to relax his grasp of an object for many seconds, even though he makes strong associated movements with his right hand. He shows a similar inability to relax other muscles of his left arm. The left leg also is somewhat affected. Such a condition of defective inhibition of protagonists—for it is apparently

[1] This condition has been noticed by Brissaud and Marie.

[2] H. G., under Dr. Risien Russell and Sir Victor Horsley.

[3] A. J., under Sir William Gowers and Sir Victor Horsley. From this patient Sir Victor Horsley has since removed by operation a large endothelioma of the right frontal lobe, which was situated close to the mesial plane and spread backward under the sensomotorium in its upper part.

not a sequel to defective innervation of antagonists—may be due to impairment of the specific functions of the sensomotorium, and not to a pyschomotor abnormality. There is considerable reason to believe, however, that it points to impairment of function of the corpus callosum. In a footnote Liepmann [43] says that van Vleuten has shown him a case of cerebral tumour presenting the same feature—probably the same as van Vleuten's recent case [78]. Further reference will be made to this "tonic perseveration" in a subsequent paragraph.

(4) *Inattention, Incapacity for Retaining Impressions.*

Other general, and important, determining factors of apraxia are amnesia, inattention, and defective capacity for retaining recent impressions (*Merkfähigkeitsstörung*). The *rôle* played by these can never be negligible, but, on the other hand, we must beware of contentedly attributing everything to their action. Inattention is usually obvious, and its influence therefore ought to be excluded with relative ease. Jackson's patient [25], who could not be made to look in any particular direction, although he seemed on the alert to act, and was all the time doing something with his muscles, can scarcely be accused of inattention. A patient of Pick's [68] applied a match to a stick of sealing wax so that the wax dripped off, but when handed a seal he pressed it on the stick and not on the molten wax. Pick thinks this incident indicative of inattention on the part of the patient, and of inattention alone. Marcuse's [54] case of senile dementia exhibited profound disturbance of memory. Her impressions were fleeting in the literal sense of the word. When told to pour water out of a carafe into a glass and replace the stopper she came to a standstill in a second or two, and asked what she had to do. We may, if we choose, describe the condition, with Marcuse, as one of "amnesic apraxia," but the phrase is otiose. It appeared that those movements were best carried out which awakened the greatest number of associations, and therefore complexity of movement was of secondary importance. The patient had difficulty in bringing her finger-tips together on request, though she used a knife and fork well; she could peel potatoes, but could not make the military salute. Her forgetfulness was such that in a few seconds she could no longer repeat what had been said to her; the repetition of three numbers was nearly always impossible. Bonhoeffer's [8] patient suffered from a similar incapacity for retaining impressions; visual, auditory, tactile, kinæsthetic impressions alike he was powerless to recall in about ten

or fifteen seconds. He could not bring the immediate past and the immediate present together. It is of interest to note which are the movements that are least likely to suffer in a case of apraxia. Dr. Jackson has held that the most automatic movements are the last to be affected, but it seems to me Marcuse furnishes weighty evidence in support of the view that those movements are best preserved which have the greatest number of associations—which is not quite the same thing. I have seen a male patient[1] with cerebral abscess in the left centrum ovale (posterior part) who failed to make any recognizable and suitable movement with his non-paralysed left hand when a pair of scissors, a pencil, a knife, a key, were in turn given him. But no sooner was a pipe handed him, with the bowl towards him, than he quickly reversed it, put the mouthpiece in his mouth, and went through the apposite pantomime of smoking. The movement of cutting with a pair of scissors is surely automatic enough, but the associations of the movement, for a man at least, are not far reaching, whereas those awakened by the sight of a pipe are more potent. It has been noticed by Heilbronner [22] that in testing female apraxic patients he has never once had occasion to remark that they made the movements of smoking in mistake for some other.

One may, I think, include under this section those cases where the patient makes mistakes in eating or in dressing. One of my cases,[2] already referred to, spent an unconscionable time in dressing and in eating his breakfast. It was observed, on several occasions, by the Sister of the ward that he took a few mouthfuls of porridge, then had a drink of tea and a bite or two of bread, then sometimes he treated himself to a spoonful (or considerably more) of marmalade by itself, then back again he went to his porridge, then perhaps he would address himself to his egg, and so on. It has happened that after finishing the other parts of his breakfast he had still porridge to take. Pick [65] had a patient who used to keep his food an interminable time in his mouth, and who never seemed to "get any further" with his meals.

In not a few of the recorded cases inability to dress properly has been observed. Laquer's [35] patient put on his stockings after he had put on his shoes. In Jackson's [27] case of imperception the patient put her things on wrong side before. The patient[3] just referred to made mistakes of a similar nature. He got into difficulties with his

[1] S. M., under Dr. Aldren Turner and Mr. Ballance.
[2] S. C., under Dr. Risien Russell.
[3] S. C.

shirt and his waistcoat; he put his shirt over his bed jacket, and his waistcoat over his coat. It seems clear that in these examples—which are only a few out of many—the defect is of an ideational type, partly dependent upon impaired recognition, but more directly the sequel of inattention and incapacity for retaining impressions.

There is a curious feature in some cases of apraxia which deserves to be mentioned. They evince indifference to their mistakes and show a somewhat surprising inability to profit by these mistakes. Even where the correct movement is executed before the patient's eyes, even though he expresses his knowledge of what is required, he proceeds to repeat the mistake unconcernedly. The explanation of this *Nichtkorrektur* is not perhaps obvious. It may lie in the fact that the attention and capacity for retaining impressions of the apraxic patient are at fault. In some cases, no doubt, such is the most satisfactory view to adopt. On the other hand, one is struck by the rather unreasoning assurance of some apraxics that the movement which they have just executed is the correct one. A patient[1] already referred to, when asked to put his forefinger on his chin, put it on the top of his head instantaneously, with a smile as of satisfaction, and repeated the mistake a moment later, though he was shown what to do. When told to put his left hand on his right ear, he put his left forefinger into his left eye, without a moment's deliberation, and when asked if he had done what was asked, he nodded in affirmation. Thus a certain absence of deliberation may very fairly be held responsible for the errors, an absence of deliberation not unlike that which occurs in the "short-circuit reaction" (*Kurzschlussreaktion.*) There can be little doubt that knowledge of one's own state of mental impairment, so commonly met with in aphasics, is much less frequent in cases of apraxia. Apraxics do not seem to learn; they do not, as a rule, appear distressed at their imperfections. This point is also alluded to by Heilbronner [22].

By the aid of Wernicke's scheme of the reflex psycho-physical arc concerned in the translation of a sensory impression into an act we may summarize what we have learned of the factors in the production of apraxia.

Let us take the simple instance (Kleist [31]) of the sight of a rose suggesting the idea of my picking it and putting it in my buttonhole.

In this scheme *s* stands for an impression in a sensory projection field—in our instance a visual impression. A is the idea most intimately associated—in our case a rose. Z is the idea of the result of the action

[1] W. P.

suggested by the idea of the rose, the idea of the object to be attained (*Zielvorstellung*, *Erfolgsvorstellung*), which is, to put the rose in my buttonhole. Finally, *m* is the idea of the movement which is to work out the aim- or object-idea; it is the movement-idea (*Bewegungsvorstellung*) of plucking the rose, &c. In accordance with this idea of movement follows the actual innervation of the sensomotorium. *s*—A is the psychosensory, A—Z the intrapsychical, and Z—*m* the psychomotor limb of the reflex arc.

Now, leaving out of account afferent and efferent defects of the lower levels, ataxia and sensory loss on the one hand, with motor paresis or paralysis on the other, we have already seen that dyspraxia or apraxia will result from lesions of the psychosensory path—agnostic apraxia from imperfect identification. We have also seen how elaborate the

FIG. 1.

process of recognition is, how various are the elements in that process, and how a sensory agnosia or an ideational agnosia may arise. Thus the A of the scheme becomes highly intricate, and its influence on the rest of the arc correspondingly manifold.

The segment A—Z of the arc may be the seat of pathological changes which undermine its function, and consequently cause apraxia. Some reference has already been made to this question. Disturbances of attention, of association, of concentration, exert their influence on A—Z; many of the phenomena of dementia, delirium,[1] &c., will be found, on

[1] In "Neurological Fragments" (*Lancet*, March 5, 1892) Dr. Hughlings Jackson published a case of agnosia in delirium, with secondary agnostic apraxia, of which he has given me the following illuminating analysis. The case was that of a sack dealer who was delirious during erysipelas. The house surgeon opened a small abscess in one eyelid while the patient was in a strait-jacket. The patient's account of these circumstances was that he had been to a public-house, that the landlord fastened him down with two sacks, and then poked out one eye. Dr. Jackson writes :—

"I send you a diagrammatic exposition of the sack-dealer's delirium distinguishing the two opposite elements of that double symptomatic mental condition into (*a*) the negative element (imperception) and (*b*) the positive or super-positive element.

"(*a*) The negative element, the patient's '*not*-knowings,' his imperceptions (samples of them), are as indicated by the series of five words in the following : (1) *Hospital*, (2) *house*

analysis, to have their origin at this point. A few examples have already been quoted, and others will be obtained in the papers of Liepmann [43], Bonhoeffer [7], Heilbronner [22], &c.

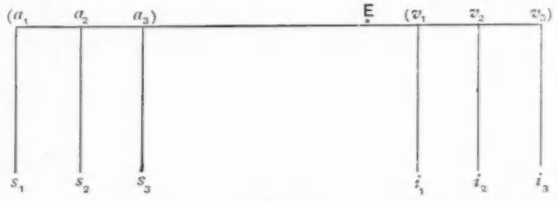

FIG. 2.

I have also indicated the results of defects in Z and Z—*m*. Interruption of Z—*m*, *i.e.*, inability to work out or carry into effect a correctly sketched idea of an action, where the sensomotorium is intact, causes pure motor apraxia. But Z is just as complex as we have seen A to be. Let us take Kleist's example once again. If a cigar and matchbox lie before me, and my perception and recognition of these objects are normal, then follows—the intrapsychical path being supposed normal also—the complex aim-idea Z, which consists of the idea of the cigar lit and in my mouth. Z itself is not identical with the idea of the various movements required to effect this purpose, but it is linked with the "working-out idea" (*Verwirklichungsvorstellung*), which is the idea of an elaborate movement-complex, made up of the ideas of a greater or less number of movements, viz., the idea of cutting a cigar, putting it in my mouth, picking up the matchbox, opening it, taking out a match, striking it, lighting the cigar, drawing

surgeon, (3) *strait-jacket*, (4) *eyelid*, (5) *surgical operation*. These things the patient did not know.

"(*b*) The positive (or super-positive) element, the patient's 'wrong-knowings,' his illusions (samples of them), are indicated by the series of five words in the following: (1) *Public-house*, (2) *landlord*, (3) *two sacks*, (4) *eyeball*, (5) *assault on eye*.

"Although we commonly think of such a case as that of (*b*), that the mental condition is of wrong-knowings, and that these are false perceptions (illusions), that is only how the story is taken by bystanders. This patient's 'illusions' were really *his knowings*, that is to say, they were *true for him*; they were *his* perceptions. Briefly, taking for illustration only (*a*) (1) *hospital*, and (*b*) (1) *public-house*, the patient was, to the observation of bystanders, bodily in the London Hospital; before the onset of his delirium he was mentally there too. But when become delirious, he was *mentally* in a public-house, most likely in one he had often been to. In fact, the præ-delirious man, the man in health, and the delirious man, the patient, were, to a great extent, two different persons. The hospital was part of the præ-delirious man's environment; the public-house was, for a short time at least, part of the delirious man's environment."

in, puffing out. The complexity of each of these ideas is obvious if we think for a moment of the necessary individual movements of fingers, hands, lips, &c. Corresponding to these working-out ideas are the various innervations, and finally the actual movements themselves. Wernicke's scheme is accordingly modified by Kleist in this way :—

E is identical with Z, which is connected with v, the working-out idea ; and it is, in turn, subdivided into a group of working-out ideas, v_1, v_2, v_3 ; corresponding to each is an i, the sign for the appropriate innervation in the motor region of the cortex. According to Wernicke, m represents the kinæsthetic image of the movement as well as the innervation, whereas it is better, with Kleist, to regard the kinæsthetic idea as an integral part of the working-out idea, along with visual and tactile ideas. In this scheme v—i is the psychomotor path ; the connections of E with v, and of the various v's with each other, are to be regarded as belonging to the intrapsychical path. Dissociation of the qualitative (sense) components from the spatial components of the various a's produces sensory agnosia ; dissociation of the spatial components of the various a's from each other produces ideational agnosia. Separation of the visual and other sense elements from the kinæsthetic element in each of the working-out ideas (v_1, v_2, v_3, &c.) causes motor apraxia ; separation of the various working-out ideas from each other explains ideational apraxia. Instances of these have already been described in previous sections. For fuller analysis of this part of the subject and for more comprehensive diagrammatic representation of the sensori-psycho-motor arc, the reader may consult Liepmann or Kleist.

Diagnosis.

After the definitions and analyses and clinical examples that have been selected to illustrate apraxia, a detailed differential diagnosis is a work of superfluity. In the course of this communication we have seen what apraxia is likely to be confounded with, and we have emphasized the necessity of excluding motor or sensory paralysis. Of course, a minor degree of sensory impairment may exist, as was noted in Liepmann's original case, but what has to be considered is whether any such impairment will or will not account for the apraxia. Undoubtedly the greatest difficulty is in some cases of cerebral ataxia (*Rindenataxie*). Cerebral ataxia has not been so carefully studied as spinal ataxia, but it may be remarked that we may have (1) cases where a lesion of the sensory centripetal tracts, involving loss of kinæsthetic impressions, is

present, and (2) cases where the lesion causes interruption or loss of kinæsthetic images. A cortical lesion may destroy either the terminations of the sensory tracts conveying kinæsthetic impressions, or the anatomical area subserving the storage of previous kinæsthetic impressions, or both. In this last case the condition which results is no longer pure ataxia, in the sense of impairment of coördination from loss of the controlling influence of afferent impulses, but a combination of ataxia with something else, which is partly of the nature of apraxia or of mind-palsy (*Seelenlähmung*). The apraxic patient who puts his finger in his ear instead of on his chin is not ataxic. But some of the amorphous movements of apraxics are less easy to distinguish. It is of assistance to remember that the ataxic man is unstable in all his ways, whereas the apraxic may perform certain movements without the semblance of ataxia. The simpler the movement, the less the ataxia; the more elaborate the movement, the grosser the ataxia. But the apraxia of the patient bears no constant relation to the complexity of the movement. What he does is often accomplished in such a way as to make us feel that he has not understood the directions, or has forgotten how to perform the movement, or at least cannot awaken the suitable innervation. In ataxia Förster [15] notes that the prime movers are always innervated with promptness, whereas it is a common occurrence in apraxia for these prime movers to fail, while the synergic muscles function conformably to the intended innervation of the others. Afferent impulses determine the "how" of the proposed movement in its finest details, but never the "what."

Of the relation of hysteria to apraxia much might be said. That agnosia and asymboly of functional, *i.e.*, hysterical, origin occur is well recognized, and they entail apraxia in the usual way. As I have more than once hinted at the impossibility of adequately handling the question of agnosia and of other general mental disturbances in this review, I shall not venture further into the interesting field for observation and study which the connection of hysteria with apraxia opens up. Some, at least, of the mental symptoms of hysterical subjects are due to inattention or incapacity for retaining impressions. Some cases show types of perseveration which are identical with those with which we have already dealt. Others exhibit apraxia (or akinesia, rather) from loss of kinæsthetic images. A patient[1] with complete loss of superficial and deep sensation in her left arm performed all ordinary movements with that limb quite readily, on request, so long as her eyes were open,

[1] S. McG., under Dr. Ormerod.

although it was observed that not invariably was her gaze fixed on the part being moved. If her eyes were shut, practically no movement was executed at all, though she maintained that she *thought* she had made the movement. As the arm did not move, there could be no kinæsthetic impressions. If, then, the patient *thought* there was some displacement of the limb, the corresponding kinæsthetic images or memory pictures may have been called up, but may have failed to awaken innervation.

The reader will find much material suggestively handled in a paper by Raecke [72] on the so-called "twilight states" (*Dämmerzustände*) of hysteria.

I should like to take this opportunity of directing attention to certain disturbances of motility which may occur in acute chorea. In an ordinary case of Sydenham's chorea the examiner is usually able to distinguish three types of motor affection: involuntary movements, incoördination of voluntary movement, and muscular asthenia. These three may be present in varying degree, and indeed they may not all be discoverable. But in some cases there is a change which is definitely of a psychomotor nature, and which has not received investigation as far as I am aware. I do not refer to what has been called paralytic chorea [17], where the patient "loses the use of a limb." This is a condition of akinesia, of inaction without paralysis. The limb may become immobile, without any spontaneous movement, and the patient may have recurring attacks of this nature. Recently, however, I have had occasion to observe some cases in which there was distinct perversion of movement, in which a given movement was either not performed or replaced by a wrong one, and this apart from any incoördination. In a case[1] of this kind the following points were noted:—

Put your right hand on the top of your head	+
Put your left hand on the top of your head	Made a sudden movement in the proper direction, but stopped opposite the left ear, and then put her hand on her left ear.

I remonstrated with her and asked whether she had done what was wanted. She replied, "I can't do it."

Put your right forefinger on your nose	+
Put your left forefinger on your nose ...	Made an abrupt movement in the direction of her mouth, stopped opposite her chest and put her hand with the palm down flat on her chest.

[1] E. D., under Dr. Aldren Turner.

In this instance also the patient said "I can't." Although the movement was initiated properly, she ended by making a wrong movement, in spite of her expressed intention.

Put your right forefinger in your left ear	+
Put your left forefinger in your right ear	At once put her left hand on to her chest, and let it rest there.

I asked if she knew what was wanted, and she answered in the affirmative, but repeated that she could not do it.

The patient was able to open and shut her eyes, put out her tongue, &c., in the usual way. With her left hand she was perfectly able to grasp and relax, she was able to flex and extend at wrist and elbow, and to move her arm at the shoulder. On the whole, the involuntary movements which she exhibited were worse in the left upper extremity than in the right, but such incoördination as was present was practically equal on the two sides.

In the consideration of these phenomena the description of her physical symptoms makes it clear that the former can be attributed neither to incoördination nor to the greater amount of involuntary movement on the left. Are they, then, akinetic in nature? It is true that such muscular asthenia as the patient revealed was possibly of greater incidence on the left side, but it has just been stated that various ordinary simple movements were executed very well by the left arm and hand. The view which commends itself to my mind is that in this case there is a degree of apraxia or parapraxia for certain movements of a reflexive nature, and this parapraxia is unilateral. It is probably transcortical in origin, due to a partial functional isolation of the right sensomotorium. That some at least of the phenomena of chorea are attributable to transcortical disturbance has been recently shown by Kleist [32]. In this connection we do well to remind ourselves that in acute chorea Poynton and Holmes [70] found vascular and nerve-cell changes in every region of the brain and brain-stem.

Relation of Apraxia to Aphasia.

The study of the relation of apraxia to aphasia, and in particular to agraphia, cannot well be entered on except *in extenso;* we may, however, indicate in a general way the analogies between these disturbances of cerebral function.

In right-handed persons the lesion which produces aphasia in any of

its varieties is in the left hemisphere. Similarly, apraxia is very much more frequent in disease of the left hemisphere than of the right in right-handed individuals. Aphasia is cortical, subcortical, or transcortical in origin. Apraxia, as far as we know, is always supracapsular, and may be either cortical, subcortical, or transcortical. The two are not necessarily associated. We may have aphasia without apraxia or apraxia without aphasia.

Speaking generally, we have in Broca's area a centre for the co-ordination of movements requisite for speech: in this area movements of tongue, throat, palate, larynx, &c., are combined prior to the actual innervation of the cortico-muscular apparatus, which takes place in the sensomotorium proper. There is considerable reason to believe, as we shall see, that there is an analogous "centre" for the coördination of certain movements, or movement-complexes, of the limbs, in the first and second frontal convolutions of the left side, and that movements are here combined ideationally, to be innervated in the sensomotorium. As Broca's area controls bilateral muscles, so the eupraxia "centre" guides the movements of both sides of the body, which must obviously depend on intactness of the corpus callosum.

In motor aphasia we have a form of apraxia, viz., apraxia of the speech musculature. The motor aphasic can move the muscles of his tongue, throat, &c., but cannot reproduce the combinations of their movements requisite for the act of speaking. Similarly the apraxic patient can move his limbs, but cannot reproduce certain combinations of movement which are required for the performance of certain acts. Apraxia has been called aphasia of the extremities. Speech is laboriously acquired by the child, chiefly through an ever-increasing store of auditory images, whereas for the acquisition of movement—in the wide sense of limb movement—he is to a great extent dependent on visual and kinæsthetic ideas. As the motor part of speech depends almost entirely on the calling up of auditory word images, so the awakening of visual and kinæsthetic images is essential for the execution of limb movements. If the patient cannot revive auditory word images he cannot speak spontaneously, though there is no paralysis of the muscles concerned; if he cannot revive kinæsthetic images he cannot move his limb spontaneously, though it is not paralysed.

Aphasia may be determined by lesions of the centripetal limb of the psycho-physical arc resulting in word-deafness and word-blindness. The existence of these entails aphasia. Similarly, agnosia may entail defects of motility. We have already seen that word-deafness and word-

blindness are merely special varieties of mind-blindness and mind-deafness, *i.e.*, of agnosia.

Agraphia and (instrumental) amusia are varieties of apraxia, since in a pure state they are affections of motility where there is no paralysis or incoördination. They are, however, highly complex disturbances. The idea of a word is a combination of the auditory image of the word's sound, the visual image of its written or printed appearance, the speech kinæsthetic image, and the graphic kinæsthetic image. Writing is the result of the excitation of the centres for graphic kinæsthetic ideas, and these may be stimulated from the auditory image centre, the visual image centre, the speech kinæsthetic centre, or from the centres for ideas of objects. There may therefore be considerable disturbance of one or other receptive centre without abolition of the power of spontaneous writing. Should the afferent side be impaired to any extent, we should have agraphia of sensory origin. But the afferent apparatus may be perfect, and yet the patient may be unable to revive graphic kinæsthetic images; he is agraphic, without any paralysis; he has apraxia of the movements for writing.

There are cases on record where an individual has been unable to play a musical instrument, with the working of which he was familiar, as the result of some lesion. He has no motor affection whatever beyond the fact that he cannot make the requisite movements of fingers and wrist. Innervation of the cortical area concerned is impossible, although the patient may be able in idea to sketch the movements correctly; if he cannot revive the kinæsthetic or visual elements in what has been called the working-out idea of the movement, he cannot voluntarily effect the corresponding innervation in the area for movements of the extremities.

It is undesirable to venture farther at present along the lines that have been merely indicated; another occasion will be utilized to discuss these questions adequately.

Pathological Anatomy.

The localization of the pathological processes which determine the production of the various types of agnosia is well known. Since the important experiments of Munk on the occipital cortex vast material has accumulated to corroborate his views on the localization of mind-blindness, and our knowledge of the cortical areas concerned where other forms of agnosia are clinically manifest is almost equally exact. Thanks to the labours of many scientists and clinicians, the functions of

a considerable portion of the cerebral cortex are thoroughly established, and the demonstration of the frequently transcortical nature of the changes determining the agnosias leaves no room for dispute. In regard, however, to the lesions which underlie ideational agnosia, or ideational apraxia, for that matter, there is little to be said that is definite. It is clear, from our sketch of the psychological basis of these conditions, that they can only be caused by a general disintegration or dissociation of centres that normally are in harmony, and such a dissociation is not likely to occur from any local or focal change. We have seen instances of these ideational apraxias and agnosias in alcoholism, senile dementia, delirium, post-epileptic confusion, &c., where, under the influence of some toxin or some general pathological process, the function of the whole cortex must be seriously at fault. Yet even in these cases there is no valid reason why the work of analysis should not eventually enable us to subdivide and localize, if we proceed slowly and surely from the known to the unknown. Bonhoeffer [7] has been led, from a study of the delirium of alcoholism, to maintain that acute exacerbations in that condition may produce clinical symptoms which point to definite and localizable areas of the cortex.

It has happened that in cases where the clinical picture included apraxia the changes in the brain, subsequently disclosed, were too widespread to be of any localizing importance. Stransky [76] had a patient who presented the symptoms of echolalia and echopraxia, paralexia and paragraphia, and typical perseveration, whose brain was subsequently found to be in a state of diffuse cerebral atrophy, apparently most marked in the neighbourhood of the left supramarginal gyrus. Marcuse's [54] patient, who presented characteristic apraxic symptoms, with gross defect of memory and incapacity for retaining impressions, was an arteriosclerotic, and on examination there was discovered simply a diffuse atrophic change in which no localisation was possible. Pick [67] has described a case of mixed apraxia in so-called senile dementia, where the morbid appearances were those of cerebral atrophy. Nevertheless, he also holds that we are learning to regard dementia as a mosaic of partial dementias, localized or localizable, and that this has an obviously important bearing on the question of apraxia. He suggests that differences in the degree of the atrophic change may be found in association as opposed to projection cortical areas.

It is more with the pathological anatomy of motor apraxia that we are here concerned. Since the publication of Liepmann's case he and Maas [51], van Vleuten [78], Hartmann [19], Abraham [2], and others

have reported cases of motor apraxia which are of the first importance, inasmuch as clinical observation has been followed by complete pathological examination. In the succeeding paragraphs the term apraxia, unless otherwise qualified, is used to signify motor apraxia in Liepmann's sense.

The original case of apraxia (Liepmann's) is somewhat unsatisfactory from the pathological standpoint. It will be remembered that the patient's state was one of motor aphasia and right-sided apraxia, with considerable alteration in cutaneous and deep sensation, weakness of the left side of the face, and bilateral apraxia of head, neck, and face; in addition, he exhibited a form of mirror writing in his left hand, which was also somewhat clumsy in performing certain tests, and occasionally showed the phenomenon of "tonic perseveration." The patient's condition altered very considerably for the worse before he died. At the *post-mortem* it was found that the whole of the corpus callosum, with the exception of the splenium, was softened, and contained scarcely a single nerve element. In the left hemisphere there were two foci of softening in the white matter underneath the first and second frontal convolutions, at the area where the callosal[1] fibres enter the hemisphere, extending partly under the third frontal. In addition, there was a large subcortical cyst beginning under the lower third of the post-central gyrus and spreading back through the parietal lobe beneath the supramarginal gyrus to end at the posterior part of the angular gyrus. In the right hemisphere was a focus of softening in the internal capsule, involving chiefly the fibres for the left face, arm, and leg, and another one in the neighbourhood of the supramarginal and angular gyri. If we refer for a moment to the scheme of the sensori-psycho-motor arc, we are reminded that apraxia is caused by an interruption in the path c—i, in other words, that the sensomotorium is isolated from the rest of the cortex. Liepmann predicted a series of lesions in the left hemisphere of his patient sufficient to cut off the Rolandic area from the rest of the brain, and his theory is confirmed by the findings at the autopsy. The objection has been raised by von Monakow [57] that it is a common and not always justifiable custom to associate the chief clinical symptom with the chief pathological lesion. Liepmann's patient suffered from arteriosclerosis, and in cases of generalized cerebral vascular sclerosis no insignificant part of the local or focal symptoms may be due less to direct interruption of tracts than to the effect of deficient nutrition on distant parts of the cortex. This doctrine

[1] Callosal is used in the sense of belonging to the corpus callosum.

of "diaschisis" (*Fernwirkung*) is considered by von Monakow to be of special importance in cases where there is disturbance of associations, as in apraxia. Be this as it may, the lesions in Liepmann's first case were sufficiently definite to suggest further study along similar lines.

In 1905 the same observer published a paper [42] based on the results of the examination of 89 patients, 42 of whom had left hemiplegia, 41 right hemiplegia; 5 had aphasia but no hemiplegia, and 1 was apraxic only. In these cases the non-paralysed hand and arm were carefully tested as regards their power to perform certain movements. Nearly all the left hemiplegics were able to execute given movements with the right (non-paralysed) arm. No fewer than 20 of the 41 right hemiplegics failed to execute the desired movements with the left (non-paralysed) arm. Of these 20 but 14 were aphasic; in other words, 6 non-aphasic right hemiplegics were unable to make certain movements with the non-paralysed left arm. Of the 21 right hemiplegics who were not apraxic in their left arms only 4 were aphasic. The first general conclusion is that apraxia is chiefly found with supracapsular lesions, especially with those which occasion paralysis of the right arm. That the patients were not word-deaf is clear, because in other ways they understood the requests, and it was noted that no improvement took place even though the examiner made the correct movement before their eyes for them to imitate. Again, apraxia and aphasia are not inevitably associated. The facts indicate that what the left hand can do is not in great part its own (*i.e.* the right hemisphere's) possession, but is loaned to it by the left hemisphere.

Only a few months ago Liepmann and Maas [51] read an important communication to the Medical Society of Berlin concerning a patient with right hemiplegia. He had complete agraphia in the left hand and severe general apraxia of the left upper extremity. The agraphia was evidently part of the apraxia. *Post mortem*, the right hemiplegia was accounted for by a lesion in the pons, while the right hemisphere was normal throughout, and in the left hemisphere there was a lesion of the first frontal convolution and of part of the paracentral lobule, and destruction of almost two-thirds of the corpus callosum on the left side. It would be difficult to exaggerate the importance of this case, as we shall see immediately.

In the discussion which followed Rothmann [73] said that he had had two left-handed patients with left hemiplegia and right apraxia. They had agraphia of the right hand as well, though they could speak and read. On the analogy of the preceding case these latter cases

seemed to show that the right apraxia was the sequel of the lesion in the right hemisphere.

About the same time an equally significant case was recorded by van Vleuten [78]. The patient had been sent to an asylum with a diagnosis of dementia paralytica. He had neither word-deafness nor word-blindness, but he experienced slight difficulty in finding words and was occasionally paraphasic. His right hand and arm, and to a less extent the leg, showed a general tremulousness which increased with muscular effort, and in addition they presented the feature of "tonic perseveration" already referred to, and this in a pronounced degree. Once the patient grasped anything in his right hand he was unable for a time to relax his grasp in spite of every effort; the same phenomenon was observed in other muscular groups in the arm, and to a less extent in the leg. The tremulousness and the perseveration mechanically hindered the execution of various movements with the limb, but as far as observed it was certainly eupraxic. The left hand showed a fine tremor, and in addition the left arm and hand were markedly dyspraxic or apraxic, in spite of the examiner's performing the correct movements in front of the patient. There was no paresis discoverable, but the patient either failed to execute a given movement at all or made a quite erroneous one (*Bewegungsverwechselung*).

Under observation his state gradually became worse, his right limbs became weaker, and the tremor disappeared; then they became dyspraxic, though never to the same extent as the left, and finally they were completely paralysed. His speech failed greatly before death. From beginning to end of the case neither optic neuritis nor any of the cardinal general symptoms of intracranial tumour was present. At the autopsy a large sarcoma was found in the left hemisphere, which had destroyed the white substance of the limbic gyrus and the cingulum, the whole of the left half of the corpus callosum and part of the right genu of the same, and the centrum semiovale of the frontal lobe. The cortex of the three left frontal convolutions was intact. The accompanying drawing (Fig 3) is copied from van Vleuten's paper, and shows the condition in a coronal section at the level of the tips of the temporo-sphenoidal lobes.

The extreme instructiveness of this case lies in the production of a left-sided dyspraxia by a lesion which has done little else than destroy callosal fibres. The left sensomotorium is intact, as are the cortical and subcortical areas of the temporal, parietal, and occipital lobes.

In 1907, further, Hartmann [19] adduced corroborative evidence of

the importance of the frontal lobe and the corpus callosum in the determination of apraxia. His contribution contains three excellent clinical studies of apraxia, with the *post-mortem* findings in each instance.

The first case was a tumour of the left frontal lobe, involving the left half of the corpus callosum, destroying the genu and sending a process through to the white substance of the right frontal lobe. It implicated the lenticular and caudate nuclei, and pressed on the internal capsule. The cortex of the left frontal pole was destroyed, but the posterior third of the upper and middle frontal gyri was intact for the depth of about 1 cm. Clinically, the patient showed marked distaste for spontaneous movements, and lay for hours in one position, with eyes

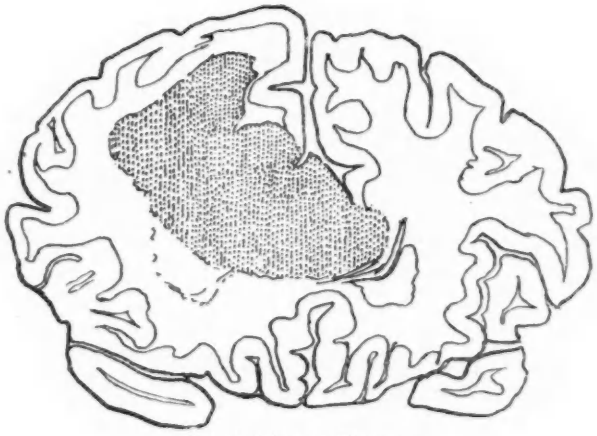

FIG. 3 (*after van Vleuten*).

closed. All movements in response to sensory stimuli were performed very deliberately. There was no particular weakness of the right arm or leg. Complete apraxia existed for right hand movements, while those of the left hand, if at all complicated, became apraxic.

In the second case there was a tumour of the corpus callosum, which spread along the mesial aspect of the left hemisphere as far as the calcarine fissure. The central gyri and projection paths were not primarily involved, and secondarily only in so far as changes in them from corpus callosum degeneration were concerned. Of the elaborate clinical picture which this patient presented we need only remark that there was more or less complete apraxia of the left hand, while movements

were correctly, though very slowly, executed by the right. If his eyes were closed, the right hand moved more slowly, sometimes came to a standstill, sometimes became apraxic.

Among the many interesting features of this case, of which I have given the merest sketch, is the difference in the function of the two upper extremities, though neither was paresed nor paralysed, nor was there any sensory loss. So long as the impressions from various sensory centres served to stimulate motility, so long was the patient able to perform eupraxic movements, however deliberately, with his right hand and arm; but in the case of the left arm the coöperation of the other senses was insufficient, and his apraxia amounted almost to akinesia. Where both hands were used for some object he was hopelessly apraxic. From memory alone he was unable to make any movement with his left arm, and very few with his right.

In the third case there was a cyst in the middle of the right frontal lobe, independent of the lateral ventricle, which injured the cortex over the second right frontal convolution and reached the under surface of the cortex over the third frontal. Clinically, the patient was unable to grimace on request or to imitate grimaces; he had difficulty in making given movements with his tongue; his right arm was normal, while with his left he frequently failed to perform set movements, making either amorphous ones or else little movement at all. There was no parapraxia. In the handling of objects no defect was observed on the right side, on the left amorphous or akinetic movements were made. With either hand he imitated well. Movements of expression (beckoning, threatening, &c.) were good on both sides. Bilateral use of the hands in indicating the nature of objects was accurate.

Thus a cortical lesion of the second right frontal convolution produced a left-sided dyspraxia, in which the simple use of objects in the left hand was greatly impaired, while the imitation of movements was perfect. The fact that two-handed movements were quite good is of peculiar interest, as it seems to suggest that the left hemisphere plays an important part in the initiation of what is accomplished by the other.

Maas [53] has recently reported a case of slight right hemiplegia and slight aphasia, where the patient can write spontaneously or to dictation with his right hand, while his left hand is typically apraxic, with conservation of motility and sensation. With this left hand he can copy movements which he cannot initiate. In this instance there is no corroboration by *post-mortem* evidence, but Maas indicates in the accompanying diagram (Fig. 4) his view of the situation of the lesion.

In June, 1907, Liepmann [48] published a paper on the physiology of the corpus callosum, based on his own cases and on some of those that have just been mentioned. He repeated his view that in right-handed persons, who constitute about 95½ per cent., the left hemisphere exercises a potent influence over the movements of both sides of the body, and that many of the movements of the left limbs are initiated in the left hemisphere. Most people can beckon or execute a threatening movement with the left arm, but these movements are impossible in certain left hemisphere lesions. The opinion expressed by Hartmann is that the first and second left frontal convolutions constitute a special association centre for the aggregation of individual movements of either side of the body into movement-complexes and for the conversion of

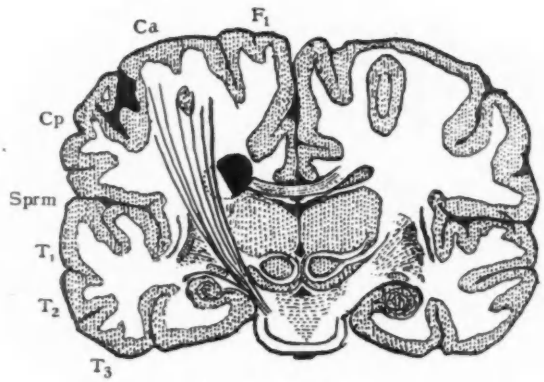

FIG. 4 (*after Maas*).

ideas of movement into the corresponding innervation. Liepmann holds, rather, that the right limb-centres depend in a way on the left limb-centres, and that the former are guided by the latter through the medium of the corpus callosum. In the accompanying diagram (Fig. 5) he elucidates his hypothesis.

(1) A lesion of the left arm centre produces greater or less paralysis of the right arm, and the left, deprived of the guidance of that centre, becomes dyspraxic.

(2) A subcortical lesion of the Rolandic area interrupts the projection fibres to the right hand, as well as the callosal fibres to the right hemisphere, according to the situation and extent of the lesion, and produces a result similar to (1).

(3) A lesion of the internal capsule, where the commissural fibres are sharply differentiated from the pyramidal, causes right-sided paralysis, but there is no left-sided apraxia.

(4) A lesion in the corpus callosum, of particular size and position, determines a left-sided dyspraxia from loss of the lead of the left arm centre over the right arm centre, while the right hand need be neither paralysed nor apraxic. A similar effect would be produced by a lesion in the left centrum ovale, which catches only callosal fibres.

(5) A fifth possibility is that a limited lesion in the white matter of the right frontal lobe may cut across the path of the fibres passing from the left frontal lobe, *via* the corpus callosum, to the right arm centre in the right hemisphere, without injuring the projection fibres from that

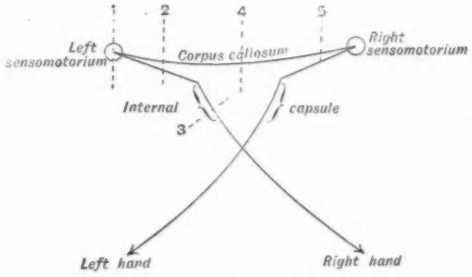

FIG. 5 (*after Liepmann*).

1. Cortical lesion.
2. Subcortical lesion.
3. Capsular lesion.
4. Lesion of corpus callosum.
5. Subcortical lesion.

arm centre to the left hand. In this case we should have a left-sided dyspraxia from a right-sided lesion. It is possible that Hartmann's third case falls into this category.

Liepmann and Maas's case, van Vleuten's case, and Hartmann's cases are therefore of peculiar interest in view of this schematization of callosal lesions.

Abraham's [2] case was one of more or less general cerebral atrophy from arteriosclerosis. It is true this atrophy of the convolutions was more marked in certain areas than in others, notably in the region extending from the post-central convolution to the occipital pole, chiefly on the left side, and in particular in the upper part of the cortex, behind the mesial end of the fissure of Rolando. It will be remembered that in

Liepmann's first case much of the region lying posterior to the ascending parietal, stretching towards the supramarginal gyrus, was involved. The more minute analysis of Abraham's case has not yet been published, and in his communication there is no reference to the corpus callosum. While the frontal lobes were atrophied, there was apparently no lesion in the centrum ovale.

At the Frankfurt Congress of 1907, Westphal [84] showed an excellent case of mixed apraxia affecting the left hand much more than the right. Apart from the motor apraxia, some of the phenomena presented by this patient were clearly due to a degree of agnosia, a feature which has been often remarked. In this case, also, only a brief report of the pathological condition has as yet been published. There was general arteriosclerosis, with internal hydrocephalus affecting the left lateral ventricle more than the right. It is scarcely desirable to refer further to the findings, as the pathological examination is incomplete; the author says, however, that to the naked eye there was no noticeable change in the corpus callosum.

Localization and Conclusions.

If we now succinctly summarize the results of clinical research and pathological investigation, we must feel that the localization of apraxia, of motor apraxia at least, is by no means so elusive as might have been suspected only a year ago. Those who have become most familiar with the subject are the most cautious in expressing opinions which are other than tentative. Nevertheless, certain facts impress themselves on us.

In the first place, apraxia may be, and has been, definitely proved sometimes to be unilateral. This unilaterality of apraxia is a fact of the greatest import. Its occurrence in one limb only, or on one side only, is already a step towards localization.

Further, apraxia is associated with lesions in the left hemisphere much more frequently than with lesions in the right. These lesions are—if we are allowed to argue from existing material, we have no hesitation in adding always—supracapsular in situation. That is, the lesions which produce apraxia are cortical or subcortical.

Again, the apraxia which results from left hemisphere disease may be homolateral or heterolateral. Recent carefully observed cases have established the significance of disease of the corpus callosum in the development of apraxia, and have supplied evidence of impairment of that structure where the apraxia is homolateral.

Apraxia has occurred where the whole of the cortex of both hemispheres has been normal, with the exception of the left frontal area. It has been present where the fibres from the upper two frontal convolutions in particular, apparently not so much projection as association fibres, have been interrupted.

Is there, then, a "centre" for eupraxia of both sides of the body in the frontal cortex on the left side? Does this "centre" bear the same relation to the motor centres for the limbs in the sensomotorium that Broca's centre does to the cortical area for the innervation of throat, lips, tongue, larynx, &c.? Some of the facts we have adduced favour this theory, and Hartmann [19] has lent the weight of his support to it. That the isolation of the left frontal cortex from the corresponding area of the opposite side determines apraxia is beyond question. That apraxia results when the left sensomotorium is functionally isolated from the rest of the cortex is also apparently well attested. It is difficult, however, to say whether the separation of the sensomotorium from the frontal cortex, or from the rest of the homolateral (occipital, temporal, &c.) cortex, or from both, is the essential element. Possibly an agnostic apraxia is determined where the associations of the sensory cortex with the upper frontal cortex are severed, while the separation of the latter from the motor cortex produces the motor variety.

The accompanying diagram (fig. 6), modified from Liepmann [48], may with advantage be combined with his other diagram representing callosal lesions.

A lesion at 1, if deep, will have as sequel the paralysis and apraxia already noted. A superficial cortical lesion here will be followed by loss of kinæsthetic ideas (Meynert's motor asymboly; Heilbronner's cortical apraxia). The motor apraxia of Liepmann's first case resulted from a lesion as at 2, whereby the left sensomotorium was cut off both from the frontal and the rest of the cortex of both sides.

Thus there are different groups of lesions of the left hemisphere which determine a homolateral or a heterolateral apraxia. We must repeat that this apraxia coexists with perfect conservation of ordinary motility, and therefore *must be looked for*. I took the notes of a case [1] of left frontal tumour some time ago, where ordinary examination revealed no abnormality in the left arm, and nothing further was remarked. Subsequent exploration discovered a left frontal tumour growing into and invading the anterior part of the corpus callosum. It is

[1] H. C., under Sir William Gowers.

at the least possible that such a case might have presented dyspraxic phenomena in the left hand, *had they been looked for.*

Our conception of the frontal lobe, and of its functional relation to the corpus callosum, the sensomotorium, and the rest of the cortex, cannot but be widened as a result of these discoveries, and with this widened conception our dissatisfaction with the indiscriminate use of such terms as "impaired intelligence," "partial imbecility," "poor memory," " defect of movement," and the like must be proportionately increased.

It is a favourite dictum of Dr. Hughlings Jackson's that the " study of the thing caused must precede the study of the cause of the thing,"

Diagrammatic horizontal section.

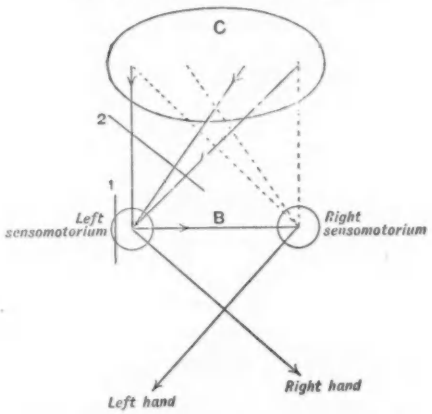

FIG. 6 (*modified from Liepmann*).

B Corpus callosum. C represents the rest of the cortex.

and we may assure ourselves that the patient eliciting of facts, too often overlooked, even in such cases as a simple hemiplegia, will be of material service in removing the reproach that is implied when we are forced to allude to the " silent areas of the brain."

SCHEME FOR THE EXAMINATION OF APRAXIC PATIENTS.

The appended scheme for the examination of apraxic patients makes no pretence to psychological completeness. Theoretically, a logical scheme should begin with the afferent apparatus; and in

addition, certain terms such as attention should not be included under a general heading, since they are, strictly speaking, psychomotor in nature; others, such as orientation, are psychosensory. It is more satisfactory, however, from a practical point of view, to commence with a general survey. The part of the scheme which would concern the question of speech has been purposely omitted. Tests for the psychosensory side of the psychophysical arc are referred to without the detail that must be supplied in full, if at all. The psychomotor part is sketched more analytically, and in it are included various methods employed by Hartmann. In a useful little paper Liepmann [44] also has indicated modes of procedure in apraxic cases.

(1) *General Psychical Condition.*

Attention (active and passive), memory (varieties of amnesia), capacity for retaining impressions, orientation in time and space; temperament, mood, depression, excitability, emotional reaction; suggestibility; deliberation, judgment, reasoning, association of ideas, hallucinations, delusions; attention to or neglect of himself, behaviour in eating, dressing, &c. Sleep, dreams, headache, giddiness, &c.

(2) *Psychosensory.*

(*a*) Simple perception, in field of sight, smell, hearing, taste, cutaneous sensibility, muscular sense.

(*b*) Recognition (and indication of recognition) of sensory impressions in regions of sight, smell, hearing, taste, cutaneous sensibility, muscular sense: localization of sensory impressions.

(*c*) Memory of, and ability to recall, former sensory impressions in same regions.

(3) *Psychomotor.*

[Throughout this examination look carefully for perseveration.]

(*a*) General: Spontaneity, initiative, general response to stimuli, immobility, restlessness, &c.; involuntary movements; range and power of voluntary movements.

(*b*) *Movements conditioned by visual stimuli.*

(i.) What response does the patient make to objects held in front of him? Does he take hold of them, with right hand, left hand, both

hands? Does he respond to gestures made in front of him (threatening, inviting, &c.)?

(ii.) Does he imitate movements performed in front of him (right hand, left hand, both)? Is there any echopraxia?

(*c*) *Movements conditioned by auditory stimuli.*

(i.) Can he make simple movements of parts of his body on request? Ask him to snap his fingers, point his fingers, separate his fingers, make a fist, &c. (either hand, both). Ask him to cough, swallow, spit, sniff, take a deep breath, sigh, yawn, put out his tongue.

(ii.) Ask him to make movements of expression. Can he threaten, beckon, make a wry face, throw a kiss, salute, clasp his hands as in prayer, &c.?

(iii.) Can he make movements for a definite object, the material not being at hand? Ask him to show how to knock at the door, catch flies, play the piano, ring a bell, count out money, turn a barrel organ, draw a cork, thread a needle, sew, &c. (The examiner ought to consider the patient's sex in this connection; the patient's occupation should also be a guide.)

(iv.) Can he, on request, make purposive movements with the objects in his hands? Can he light a match, smoke, pour out water, tie a knot in string, &c.? (*Cf.* iii., above.)

(v.) Ask him to imitate simple movements made in front of him (either hand, both hands).

(vi.) Can he make reflexive movements on request? Ask him to touch various parts of his own body which he can see, to scratch or tickle himself, to pull his moustache, &c. Ask him to touch various parts of his body which he cannot see: request him to put his hand on the back of his head, to touch his nose with his finger, to put his hand in the middle of his back, &c. Does he touch corresponding parts on examiner better? Can he make reflexive movements with objects in his hand? Ask him to brush his hair, comb his beard, brush his teeth, blow his nose, &c.

(*d*) *Movements conditioned by tactile and kinæsthetic stimuli.*

(i.) Give objects to the patient; how does he hold them? how does he use them? If he is shown the way, does his handling of them improve? Does it make any difference whether his eyes are open or shut? Can he continue a movement once begun if he shuts his eyes?

(ii.) Put limb passively into a certain position. Can he imitate it with the other? Any difference if eyes are shut? Can he imitate from right to left and from left to right?

(*e*) Movements of the arms during general movement of the body. Observe what he does with his arms when sitting down, rising up, walking, &c.

[Throughout the examination it is desirable, as far as possible, to test the hands separately, and then together.]

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Publications Recently Received.

[Notes on a book under this heading do not preclude a subsequent review.]

Beiträge zur Kenntnis der Heine-Medinschen Krankheit [Poliomyelitis und verwandter Erkrankungen]. Von Dr. Ivar Wickman. S. 292. Berlin: Karger, 1907.

In this interesting work the author puts together a clinical account of those acute diseases which affect the motor side of the nervous system, of which poliomyelitis acuta is the best-known example. He traces the epidemics which have occurred in Sweden, giving local maps and tables of incidence. It forms a valuable companion to the author's previous work on poliomyelitis, which dealt mainly with the pathology. We cannot help regretting the title of this book, which obscures its contents.

Die Funktionen der Nervencentra. Von Professor W. von Bechterew. Deutche Ausgabe in Verbindung mit dem Verfasser redigirt durch Dr. Richard Weinberg. Erster Heft, S. 691. Jena: Gustav Fischer, 1908.

This important work is the first half of an exhaustive description of the position and function of the centres and paths in the nervous system. After an introduction of eighty-two pages, the author passes to the spinal cord and medulla oblongata; here he describes the nervous mechanism underlying all the visceral functions. The present volume ends with a consideration of the conducting paths in the spinal cord. On the appearance of the second volume we hope to give this work a fuller notice.

The Influence of Alcohol and other Drugs on Fatigue. The Croonian Lectures, delivered at the Royal College of Physicians in 1906. By W. H. R. Rivers, M.D. Pp. 136. London: Edward Arnold, 1908.

These lectures contain a description of the experiments made by the author on the influence of caffeine and alcohol on muscular work and mental fatigue. The former was measured by means of the ergograph and the latter by various modifications of Kraepelin's method. Every precaution was taken to avoid suggestion; control mixtures indistinguishable from those containing the drug under investigation were taken by the subject. In many ways this work is a considerable advance in the psychological study of the influence of drugs on man. The literature of the subject is fully considered. The book is clearly written and admirably printed.

Injuries of Nerves and their Treatment. By JAMES SHERREN, F.R.C.S. Pp. 310. London: James Nisbet, 1908.

A thoroughly practical treatise on nerve injuries and their treatment, based on original research and clinical observation. The author first describes the symptoms and signs produced by complete division of a peripheral nerve and contrasts it with those which follow incomplete division. Differential diagnosis and treatment are carefully considered. He then passes to the methods of recovery and to the signs peculiar to each of the larger nerve trunks. The book is illustrated with photographs and diagrams; it is well printed and is not too large for the pocket. It will be of great value to senior students and practitioners, and the neurologist will find much both of practical and theoretical interest.

The Labyrinth of Animals. By ALBERT A. GRAY, M.D., F.R.S.E. Vol. ii. Pp. 252. London: Churchill, 1908.

The first volume of this remarkable work appeared in 1907. The author succeeded in removing the bone so as to leave the membranous labyrinth intact. Each specimen was then photographed stereoscopically. This volume deals with rodents, insectivora, cetacea, marsupials, the principal groups of birds, reptiles and amphibians.

Diseases of the Nervous System. Edited by ARCHIBALD CHURCH, M.D. An authorized translation from "Die Deutsche Klinik" under the general editorial supervision of JULIUS L. SALINGER, M.D. Pp. 1205. London: Sidney Appleton, 1908.

This translation of a German text-book of diseases of the nervous system will be of use to post-graduate and senior students; the neurologist will find little which is not familiar to him. The sections are unequal, as must be the case in a book compiled by thirty-two contributors; some, such as that of Wernicke on Aphasia, are unusually full from the author's point of view, whilst others, such as that on Cerebral Hæmorrhage and Embolism, occupy six pages only.

Anatomy of the Brain and Spinal Cord, with Special Reference to Mechanism and Function. By HARRIS E. SAUTEE, M.D. Fourth edition, revised and enlarged. Pp. 453. London: Sidney Appleton, 1908.

Suitable for a senior student, this book is too superficial for the trained neurologist. There is no discussion of divergent views, and controversial points are covered by an incomplete statement or the intricacies of a diagram. No references are given to the literature. Printing and general arrangement are excellent.

Psychiatrie für Aerzte und Studierende bearbeitet. Von Professor Dr. Th. ZIEHEN. Dritte vollständig umgearbeitete Auflage. S. 801. Leipzig: S. Hirzel, 1908.

A third edition of this well-known text-book. Its general plan remains unaltered, and all the principal features of previous editions are maintained. The notes in small print, containing references to the literature, add decidedly to the value of the book.

Mental Pathology in its Relation to Normal Psychology: A course of lectures delivered in the University of Leipzig. By GUSTAV STÖRRING, Professor of Philosophy in the University of Zürich. Translated by THOMAS LOVEDAY. Pp. 298. London: Swan Sonnenschein & Co., 1907.

A series of lectures dealing with the bearing on psychology of the nature and genesis of hallucinations and illusions, of aphasia and amnesia, of imperative ideas and delusions. Two lectures are devoted to a consideration of feeling and one to manifestations of the morbid will.

The Psychology of Alcoholism. By GEORGE B. CUTTEN, B.D., Ph.D. Pp. 357. The Walter Scott Publishing Co., New York, 1907.

A general discussion of the phenomena of alcoholism and a review of the various forms of treatment. It contains no original experimental or clinical observations.

Transactions of the Ophthalmological Society of the United Kingdom. Vol. xxvii. Session 1906-1907. Pp. 311. London: Churchill, 1907.

The reports on hereditary diseases, and especially Nettleship's history of congenital stationary night-blindness in nine consecutive generations, are for the neurologist the most interesting contents in this volume. This paper will certainly become a classic, and should be a model for all who work on hereditary disease.

Transactions of the Ophthalmological Society of the United Kingdom. Vol. xxviii. Fasc. 1. Pp. 94. London: Churchill, 1908.

The only paper of neurological interest is that by Nettleship on "Some Cases possibly allied to Amaurotic Family Idiocy." He propounds the question: What would be the fundus changes in a patient with Waren Tay-Sachs disease who succeeded in living? and suggests that some cases of congenital amblyopia with day-blindness and total loss of colour sensation may be allied to this disease.

Writers of "Original Articles and Clinical Cases" are supplied free of charge with 50 copies reprinted in the form in which the paper stands in the pages of "Brain." If reprints are required in pamphlet form, with wrapper, title-page, &c., and re-numbered pages, they must be ordered, at the expense of the writers, from Messrs. BALE, SONS & DANIELSSON, Ltd., 83-91, Great Titchfield Street, London, W.

Members of the Neurological Section of the Royal Society of Medicine can obtain the Index of "Brain" for the Volumes I. to XXIII. inclusive, that is, from its commencement to the end of 1900, from Messrs. MACMILLAN & CO., Ltd., St. Martin's Street, London, W.C., at the price of 6s. 6d., post free.

To those who are not members of the Neurological Section of the Royal Society of Medicine the price is 8s. 6d. net, and the volume may be obtained through any bookseller.

EDITOR.