THE SURGICAL TREATMENT OF EXTRAPYRAMIDAL DISEASES*

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Strictly speaking there is no satisfactory surgical treatment of any of the disorders which arise from involvement of the extrapyramidal systems. Diseases which involve the extrapyramidal components of the central nervous system are numerous and give rise to many different clinical manifestations. Only a very small minority of the victims of these diseases present problems which can in any measure be solved by surgical therapy. And even in such cases surgical measures are, at least at this moment, never curative and seldom benefit more than one of the many symptoms which are present. Even in those few cases surgical treatment usually consists of substituting an undesirable neurological deficit for an even more disabling and disturbing manifestation of the disease. There are now reasons to hope that this may not continue to be true in the future.

With few exceptions the disorders arising from lesions of the extrapyramidal systems which are so commonly seen in man are peculiar to him. Rarely has it been possible to produce in experimental animals disturbances sufficiently akin to those seen in man to permit us to make reliable investigations of these problems in the experimental laboratories. Similarly, nature has failed to provide us with animals afflicted with such diseases as those seen in man. The problem is further complicated by the fact that the central nervous mechanism which controls muscular activity in man is different in many respects from that present even in the subhuman primate, and widely different from that found in lower forms. It is thus obvious that if we are to study these diseases we must study them in man. This is not the only circumstance in which we must agree with the French philosopher, Pierre Charron, and with England's Alexander Pope that "the proper study of mankind is man", but it is one of the most outstanding.

We have not time now to give attention to the entire question of the organization of the central nervous mechanism for the control of human muscular activity. That is a full subject in itself. However, we must tarry briefly to discuss just what is meant by the term "extra-pyramidal systems".

A few years ago "extrapyramidal system" and "basal ganglia" were almost if not quite synonymous. As recently as 1928 in the index of the late Kinnier Wilson's book, Modern Problems in Neurology, we find "Extrapyramidal Syndromes. See Corpus striatum". And Grinker in 1934, in the first edition of his book, Neurology, p. 405, says:

"Numerous large and small ganglia at the base of the brain, forming together a relatively large area of tissue, comprise the extrapyramidal motor system."

Other examples could be cited but this is sufficient to indicate the inadequate conception of the extrapyramidal systems which was so recently held. Furthermore, at that time it was commonly thought that there were few if any connexions between the cerebral cortex and the basal ganglia and that the pyramidal and extrapyramidal systems formed autonomous units which functioned nearly independently of each other, yet collaborated in the dual control of the muscular system by means of some obscure, almost ethereal coordinating mechanism. The extrapyramidal system was thought to be "not directly concerned in the production of voluntary movement" (Walshe, 1941), while the pyramidal system and the cerebral cortex were generally regarded as being in no way related to those states which were commonly classified as "extrapyramidal disorders".

Although our knowledge of the extrapyramidal systems, their structure, functions and disorders, is still woefully incomplete, it has progressed far beyond the state of ignorance and confusion indicated above. It is now well established, as one might have anticipated in view of the beautiful, smooth coordination which characterizes all normal
muscular activity, that the pyramidal and extrapyramidal systems, the motor cortex and the basal ganglia and other subcortical motor centres, are all closely integrated and coordinated into one mechanism which is concerned with the control of muscular activity. The overall control of this neural mechanism is exercised through the precentral motor cortex. The extrapyramidal system is not an independent neural mechanism; neither is it a single unitary system. The extrapyramidal systems consist of a group of complex neural organizations, all of which stem directly from the precentral motor cortex.* Areas 24, 8, 2, and 19 also project to the caudate nucleus and probably must be considered as part of the extrapyramidal systems having a functional activity akin to that of the connexions known to exist between area 4s and the caudate nucleus. In all probability all of the anatomical extrapyramidal connexions between the precentral motor cortex and the subcortical centres are not known; certainly many details regarding them are still a mystery, and without a doubt the functional activity of many of these connexions is still to be learned. At the present time it is known that there are descending connexions from area 4s of the precentral motor cortex (and also from areas 24, 8, 2, and 19) to the caudate nucleus; from areas 4 and 6 to the putamen; from area 6 to the external segment of the globus pallidus; from the precentral motor cortex (areas 4, 4s, and 6) to the zona incerta, the red nucleus, the substantia nigra, and the reticular formation of the mesencephalon and pons. There is also a large group of descending fibres which pass from areas 4 and 6 to the pontine nuclei. Here the impulses are relayed via the middle cerebellar peduncle to the cortex of the neocerebellum, primarily in the cerebellar hemispheres. There is also a very heavy efferent projection from the precentral motor cortex to the lateral nuclear mass of the thalamus, but it might be reasonably argued whether these cortico-thalamic connexions are directly concerned in the control of muscular activity and should therefore be classified as extrapyramidal. I would define the extrapyramidal systems as those complex groups of descending fibre systems which are directly concerned with the control of muscular activity, which arise in the cerebral cortex and descend through various subcortical centres through a variable number of synapses but have no fibres which pass directly from the cerebral cortex to the spinal cord.

The study of the functional activity of the extrapyramidal systems is very largely dependent upon information which it has been possible to accumulate from the study of laboratory animals, particularly the subhuman primates, such as the monkey, the baboon, and the chimpanzee. How completely this information is applicable to the human nervous system is uncertain and must be inferred from inadequate observations. Even in the experimental animals, however, our knowledge of these functions is distinctly imperfect, particularly as concerns the correlation of structure and function. Although we know of a rather wide variety of extrapyramidal mechanisms there are still many situations in which we do not know which function a given system is responsible for, or when the function is known, we are often unfamiliar with the structural means by which it operates.

The various known functions of the extrapyramidal systems can be classified as follows: (1) the production of integrated primary movements of the skeletal musculature; (2) the integration of associated and ancillary movements; (3) the control and inhibition of postural reflexes; (4) the suppression of electrical activity in other areas of the cortex; (5) the imperfect and partial control of visceral and vegetative functions and their integration with the activity of the skeletal musculature.

The movements produced by the extrapyramidal systems are crude and coarse. They lack the fine, discrete, precise nature characteristic of movements produced by the pyramidal system. They are nonetheless voluntary and purposeful. The movements produced by the extrapyramidal systems tend to involve the proximal joints such as the shoulder and elbow, hip and knee, in contrast to the movements produced by the pyramidal tract which are most extensive in the digits. There is no evidence available at this time as to which of the various extrapyramidal systems is concerned in this production of voluntary movements.

Fibres from the precentral motor cortex to the basal ganglia, to the brain stem, and to the pontine nuclei where impulses are relayed on to the cerebellum appear to be concerned in the innervation of associated and ancillary movements which, although not directly concerned in the principal or primary movement, are nevertheless of great importance in the smooth, well coordinated performance of the act. The role which each one of these extrapyramidal systems plays in the integration and production of these associated movements is not clearly understood.

One of the most important functions of the extrapyramidal systems is the control of the postural reflexes. Such reflexes are obviously extremely

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* For the details and bibliography of the anatomical and physiological facts stated here see "The Precentral Motor Cortex" edited by Bucy (1949).
important in the physical economy of the organism, but unless properly controlled and their actions appropriately coordinated with voluntary muscular activity, they would greatly interfere with such activity. It is likely that different parts of the extrapyramidal systems are concerned with the inhibition and control of these various reflexes. It has been shown, however, that the strip 4s, which lies between 4 and 6 in the monkey and between area 4a and 6 in man, is probably the most important of the cortical areas so concerned. Although this strip has several descending projections, the one which is particularly concerned with the control of the postural reflexes is that which descends from area 4s through the internal capsule and cerebral peduncle to terminate in the reticular formation in the upper bulb (Magoun and Rhines, 1946). From here the inhibitory impulses are relayed on to the spinal cord via a reticulo-spinal tract which appears to be concentrated in, although not confined to, the ventral part of the lateral funiculus of the spinal cord. Although this neural mechanism is primarily concerned in the control of the postural reflexes, it is noteworthy that, at least under experimental conditions, it is capable of inhibiting all types of motor activity. Thus experimental stimulation of this system at the cortical level can arrest the clonic after-discharge produced by intensive stimulation of area 4 in the precentral motor cortex; it can inhibit spontaneous muscular activity in the extremities; it can abolish the spasticity commonly associated with light ether anaesthesia; and stimulation of the bulbar reticular formation can hold completely in abeyance movements which would be otherwise elicited by the electrical stimulation of area 4. It is not to be presumed, however, that this area 4s-reticulo-spinal system is the only extrapyramidal mechanism which is concerned in the control of postural reflexes, although it does seem to be the principal and most important system so concerned. There is definite evidence that the spasticity which develops following the removal of all of the precentral motor cortex is greater than that which develops after the destruction of area 4s alone. Furthermore, the spasticity which appears after an extensive cortical lesion of the precentral motor cortex in man is not as intense as that which commonly develops after a severe lesion of the internal capsule. Lesions still farther "caudalward", in the mesencephalon, are not commonly available for study in man but the spasticity which appears in such cases is intense and probably more intense than that associated with capsular lesions. In addition, there is definite evidence that stimulation of the anterior lobe of the cerebellum is capable of inhibit-

ing postural reflexes and that destruction of this part of the cerebellum leads to the appearance of a generalized spasticity which is akin to decerebrate rigidity. It thus seems obvious that controlling impulses descend from the cortex to the basal ganglia as well as to the reticular formation and that in these various subcortical ganglia they are elaborated and enhanced by influences from the basal ganglia, the brain stem, and the cerebellum, thus augmenting the inhibitory effect as it descends from the precentral motor cortex toward the spinal cord.

Area 4s (like areas 8, 2, 24, and 19) is also capable of inhibiting the electrical activity of other areas of the cerebral cortex. This effect is mediated through the caudate nucleus and thus follows an entirely different pathway from the impulses which are concerned in the control of postural reflexes and the inhibition of other peripheral motor responses. Whether this effect of inhibiting other areas of the cerebral cortex is directly or remotely concerned in the control of peripheral muscular activity and should, therefore, be classified, under our definition, with the other extrapyramidal activities cannot be stated at this time.

The least complete control which the precentral motor cortex exercises is over the various vegetative and visceral functions of the body. This is probably the least well understood of the various functions of this portion of the brain. There can, however, be little doubt that such control exists. It is concerned with gastrointestinal, vasomotor and cardiac activity, piloerection, and the secretion of perspiration. There is reason to believe that, although many of these functions are executed over unknown extrapyramidal pathways, the pyramidal tracts may also be concerned in some of them, notably vasomotor activities. Furthermore, there is good evidence that other parts of the cerebral cortex lying near but not in the precentral motor cortex are concerned with still other activities of this general category. Thus the frontal eye fields (principally area 8) which lie immediately anterior to area 6 are concerned with control of the pupils. Some structure in or near the spatially closely related orbital surface of the frontal lobe, uncus of the temporal lobe and anterior portion of the Island of Reil, is concerned with the control of respiration, gastrointestinal activity, and vasomotor phenomena. The importance of the control of these visceral and vegetative functions in connexion with the activity of the skeletal muscular system is obvious and there can be little doubt that such control, limited and imperfect as it is, resides in the precentral motor cortex in order to control these functions in the best interests of the total economy of the organism.
Extrapyramidal Disorders

Those disturbances which we have come to designate as "extrapyramidal" are so classified because they arise as the result of pathological lesions located somewhere within these extrapyramidal systems. Thus parkinsonism or paralysis agitans (and thus the tremor at rest which is so commonly a part of this syndrome) is associated with lesions in the substantia nigra or the globus pallidus, or often in both. Action or intention tremor, on the other hand, develops in association with lesions which destroy the dentato-rubro-thalamic system. Choreo-athetosis usually appears following a lesion of the striatum (caudate nucleus and putamen) or of the anterior half of the lateral nucleus of the thalamus. Huntington's chorea is associated with severe atrophy of the lenticular nucleus (globus pallidus and putamen), but the lesion responsible for the development of the abnormal and involuntary movements which are characteristic of Sydenham's chorea have never been accurately defined. Hemiballismus, or hemichorea as it is sometimes called, appears following severe damage to the subthalamic nucleus of Lysy. Although some of the disorders which have been listed here are associated with true neurological defects, such as the absence of associated and expressive movements in Parkinson's syndrome, we are primarily concerned here with the positive neurological abnormalities which appear in these conditions and in association with these lesions. This is one of the clearest illustrations of the dictum of Hughlings Jackson (1931) that whereas destructive lesions of the nervous system may produce neurological deficits or negative manifestations, they cannot directly produce positive phenomena. Such destructive lesions only permit positive manifestations, such as involuntary movements, to appear as the result of the release of other and intact structures to abnormal activity. For years the location of the pathological abnormality focused all attention upon the basal ganglia and intensive but futile search was made here for the neural mechanism responsible for the abnormal involuntary movements which characterize these "extrapyramidal diseases".

There had been several minor indications from time to time that the mechanism responsible for these abnormal movements was connected with the downward projection from the precentral region. Parkinson in his original description in 1817 had pointed out that the tremor of the shaking palsy disappeared if the patient developed a hemiplegia as the result of a capsular lesion, and Jakob (1923) had described a case of athetosis in which the abnormal movements disappeared when the patient became hemiplegic. Horsley, in 1909, and others had presented even more definite evidence of such a relationship when they showed that destruction or removal of the precentral gyrus would abolish the abnormal involuntary movements of athetosis. In the main, however, these observations attracted little attention. In 1925 and 1928 the late Kinnier Wilson postulated that the abnormal involuntary movements characteristic of choreo-athetosis were produced by impulses travelling over the pyramidal tract from the precentral region, and that this system had been released to such abnormal activity by the destructive lesions in the subcortical centres, particularly the "cerebello-subthalamic-cortical" afferent pathways. Although we would modify and elaborate some of Kinnier Wilson's ideas in some respects, the clinical observations of the past 20 years have, in general, substantiated his hypotheses.

In 1931 a 7-year-old girl with unilateral choreo-athetosis (and unilateral convulsive seizures) was operated upon and a considerable portion of the "arm" area of the precentral gyrus extirpated (Bucy and Buchanan, 1932). Following the operation she had no choreo-athetoid movements and in the ensuing years these movements have never returned. Subsequently other patients suffering from choreo-athetosis have been similarly operated upon and other surgeons have reported other successful cases of a like nature.* From these observations it has gradually become apparent that for the most satisfactory results in the relief of choreo-athetoid movements it is necessary to remove all of the representation of the affected extremity in the precentral gyrus, i.e., area 4, and the neighbouring parts of the first and second frontal convolutions, i.e., area 6. As has been pointed out earlier, areas 4 and 6 of the precentral motor cortex give rise to both pyramidal and extrapyramidal fibres and it would not be possible from the evidence thus far cited to determine which of these fibre systems is concerned in the production of these involuntary movements. However, Putnam (1938 a and b) and others later demonstrated that division of the anterior column of the spinal cord likewise will often greatly reduce the intensity of these movements. As such an operation would

*Occasional cases have been reported in which removal of the "premotor" area has not affected the abnormal involuntary movements of choreo-athetosis. In practically every instance it has been clear that the representation of the involved extremities in areas 4 and 6, as described above, has not been removed. Incomplete extirpations or inaccurately placed ablations only lead to unsatisfactory results but do not contradict the statements which have been made here. In the case published by Davison and Goodhart (1938) and again by Davison (Case 14, 1944) it is obvious that the extirpation was in the inferior part of the frontal lobe, well anterior to the precentral gyrus and did not encompass the representation of the right arm and leg which were involved by the involuntary movements.
divide many extrapyramidal fibres while leaving the lateral pyramidal tract intact, it is reasonable to conclude that it is the extrapyramidal and not the pyramidal fibres which are primarily concerned in mediating the nervous impulses which give rise to the abnormal involuntary movements of choreo-athetosis.

Unfortunately, the operation of anterior cordotomy has not proved highly satisfactory in the treatment of these conditions. This is most regrettable as whereas the cortical operation of necessity destroys pyramidal as well as extrapyramidal fibres and thus results in a severe degree of paralysis, the anterior cordotomy would spare the pyramidal tract and thus interfere much less with voluntary muscular activity. However, whereas the cortical procedure, when properly performed, is capable of completely and permanently abolishing the abnormal involuntary movements of choreo-athetosis, the anterior cordotomy rarely more than diminishes these movements and even when the results are the most striking, they are often not permanent. This is probably to be attributed to the fact that a division of the anterior columns of the spinal cord still leaves many of the extrapyramidal fibres intact. The following case is an example of the favourable, but temporary, results which can at times be obtained with anterior cordotomy and the contrasting more complete and permanent results which can be obtained in the same case by cortical excision.

Case Reports

Case 1.—E.M.S., a woman 26 years of age, was referred by Dr. Eric Oldberg, of Chicago. At the age of 2½ years she developed abnormal involuntary movements of her left arm and leg for no known reason. The movements gradually grew more severe, and, by 1936, when she was 23 years old, they had become so severe that she was confined to a wheel chair into which she had to be tied to prevent her being thrown out by the violent involuntary movements. On July 1, 1936, Dr. Oldberg crushed the anterior column of the spinal cord on the left side at the level of the second cervical anterior root. “Following the operation all the abnormal movements stopped immediately except for a slight, almost imperceptible, jerking of the left shoulder girdle.” Unfortunately such a complete abolition of the abnormal movements did not persist. By September the patient wrote that the jerking had returned but was not as severe as before the operation. Thereafter the involuntary movements of the left arm and leg gradually increased in severity, although they never returned to their former degree of violence.

On July 14, 1939, she was admitted under my care to the University of Chicago Clinics. There were occasional involuntary twitchings of the left side of the face. The left arm made continuous purposeless writhing, twisting movements which involved all joints—the shoulder, elbow, wrist, and fingers. There were less severe movements of the left ankle and great toe. These involuntary movements were constantly present when she was awake and ceased only during sleep. She was still confined to a wheel chair but no longer had to be tied in.

On July 27, 1939, the right precentral motor cortex was exposed at operation and that portion of it removed from which movements could be elicited in the left upper and lower extremities by electrical stimulation (Fig. 1). The extirpation also included the paracentral lobule on the medial surface of the hemisphere and the most posterior part of the first frontal convolution. However, the inexcitable portion of the precentral gyrus lying between the last point from which movements of the fingers could be elicited and the representation of the face was not removed. This, as we shall see, was a mistake.

On the seventh postoperative day slight involuntary movement of the left fingers was noted. On the twenty-fourth postoperative day involuntary rotation of the left forearm was seen. Thereafter such movements were seen only rarely until the 90th day, when involuntary movements of the left wrist and fingers were obvious and persistent. These continued but otherwise the involun-
EXTRAPYRAMIDAL SURGERY

An involuntary movement which had been so continuous and severe before the cortical extirpation did not return. It was decided that the inexcitable portion of the precentral motor cortex lying ventral to the ablation was responsible for these movements. However, as they were not severe nothing was done about them until the patient returned asking that a further cortical extirpation be made. This was done on January 26, 1943. The former osteoplastic flap was again reflected. On electrical stimulation of the precentral gyrus just ventral to the scar of the previous extirpation, movements of the left forearm and hand were produced. Further ventrally electrical stimulation elicited movements of the left eyelids, and below that point movements of the left side of the face and of the left platysma myoides. The precentral gyrus was extirpated from just above the point at which movements of the left side of the face were produced (Fig. 2). In other words, that portion of cortex from which movements of the left upper extremity and of the left eyelids were produced was extirpated. This was largely the portion of the precentral gyrus which was inexcitable at the first operation. In addition, the scarred base of the cavity left by the former operation was also removed. The cavity left after this second operation measured 6 cm. long, 1.4 cm. wide and 2 cm. in depth.

The patient has continued to return for examination at frequent intervals. She is active and does most of the housework in the home of her parents where she lives. She also does beautiful needlework, although she is only able to use the left hand to hold the embroidery hoops. The left upper extremity is otherwise of very limited usefulness. The usefulness of the left lower extremity has been enhanced by an operation on the peripheral nerves to the leg and an arthrodesis of the ankle joint and she walks well although with a definite limp. The involuntary movements have not returned some seven years after the last operation. She is one of our most appreciative patients and has been restored from a life of inactive wheel chair existence to one of comparative usefulness.

Different operations for the relief of the abnormal involuntary movements of choreo-athetosis have been performed by other surgeons. Extirpation of the frontal lobe immediately anterior to the excitable cortex of the precentral motor cortex have been made. Most of the operations of this type have been performed by Klemme (1940), and unfortunately the details as to the patients, their illness and symptomatology, the operations and the results obtained have never been published. Most other surgeons (Sachs, 1942; Putnam, 1933; and others) have not been able to obtain the fortunate results which Klemme has indicated have followed such a procedure.

Although Wilson believed that the involuntary movements of choreo-athetosis were produced by impulses travelling over the descending fibres from the precentral region he did not believe that tremor was similarly produced. However, there were other evidences that it was. As previously noted, Parkinson and later others, had noted that the tremor of paralysis agitans was abolished when apoplexy paralyzed the involved extremities. More recently Aring and Fulton (1936) showed that the intention tremor produced by cerebellar lesions could be abolished by removal of areas 4 and 6 in the monkey. With these observations to guide us, on October 12, 1937, the representation of the upper extremity was removed from the left cerebral hemisphere of a man who suffered from both tremor-at-rest and intention tremor as the result of a severe cranio-cerebral injury (Bucy and Case, 1939). This operation was followed by a complete cessation of the tremor and the tremor had not returned when the man was last heard from several years later. In the years which have followed a few other patients with tremor have been seen who were thought suitable for such an operation. Several of these have been operated upon. It is now obvious that tremor, whether at rest or of the intention variety, can be completely abolished by the extirpation of the area of representation of the involved

Fig. 2.—Sketch of the cerebral cortex (Case 1) exposed at the second operation on January 26, 1943. The site of the first extirpation is outlined and designated "1st". The points from which electrical stimulation provoked movement of the left hand, left eyelids and left cheek at this second operation are marked; those for the eyelids (Bx) and cheek (Cx) correspond to those demonstrated in 1939. The "hand" focus found on this occasion was demonstrated for the first time. The second extirpation is outlined and designated "2nd".
extremity (or extremities) in the precentral gyrus alone, i.e., area 4. At one time it was hoped that removal of only the posterior half of the precentral gyrus (area 4 which contains the Betz cells) would suffice permanently to abolish such tremor. However, such a limited extirpation proved inadequate and the tremor returned in a mild form.

That the effect of the removal of the precentral motor cortex is a precise one dependent upon the destruction of specific cells and fibres related to the affected part is clearly shown by the following case.

Case 2.—G.B., a 28-year-old woman, was referred by Dr. Adrien Verbruggen of Chicago. She had been well until January 12, 1941, when she fell from a moving automobile and struck her head on the concrete pavement. She was unconscious for the next 14 weeks. Subsequently exploratory trephination and later an exploratory osteoplastic craniotomy failed to disclose any haematoma. When the patient recovered consciousness she had an aphasia, dysphagia, a severe incoordination of the movements of the extremities, and a right hemiplegia. Her condition gradually improved but she never became able to walk. About nine months after the injury tremor appeared in the right upper extremity. It gradually increased in severity and spread to the right lower extremity. In September, 1947, a pneumoencephalogram demonstrated an increase in the size of the subarachnoid spaces over the cerebral hemispheres and a dilatation of the ventricular system.

She was admitted to the Illinois Neuropsychiatric Institute on October 2, 1947. The most striking abnormality was a severe tremor which was greatest in the right hand and arm but was also present in the right lower extremity. This tremor was present with the extremities at rest and was often so severe that the hand flapped against the side of the body unless the patient held it with the left hand. However, the tremor was much more severe whenever voluntary movements were attempted with the right extremities. There was marked limitation of voluntary movements in the right extremities and, as noted above, she was unable to walk except with a great deal of assistance, and then did so very poorly. The right upper extremity was held in a flexed position and was moderately spastic. The forearm was pronated. All tendon reflexes were hyperactive; those on the right were more active. Babinski’s sign was present bilaterally, but was more easily elicited on the right side. The abdominal reflexes were present and equal. Cutaneous sensibility (touch, pain, heat, and cold) was slightly diminished on the entire right side. There was an astereognosis in the right hand and she was unable to recognize figures written in the right palm. Her speech was quite limited and difficult. She spoke slowly and very jerkily. Her pronunciation was poor. There was a complete paralysis of the external rectus muscle of the left eye, the right pupil was slightly larger than the left, both reacted to light but there was no reaction of accommodation and she could not converge her eyes. There was a slight drooping of the right side of the face.

It was felt that this young woman had sustained a severe injury to the upper pons and midbrain, particularly on the left side, with an involvement of the left abducens nucleus, the left cerebral peduncle and the dentato-rubro-thalamic tract after it had crossed from the right superior cerebellar peduncle to the left side of the midbrain, a condition similar to that so well described by Kremmer, Rushton, and Smyth (1947). It was decided to remove the representation of the upper and lower extremities from the left precentral gyrus in the hopes of abolishing the tremor.

On October 22, 1947, under ether anaesthesia the left precentral region was exposed. With electrical stimulation (60 pulses per second, 2 sigma falling phase and various voltages up to 20) movements of the right thumb, fingers, wrist, elbow, and shoulder were elicited. No movements of the lower extremity were produced. The representation of the right upper extremity in the precentral gyrus and the gyrus up to the midline were removed (Fig. 3). The “face” area was carefully preserved to avoid interfering further with the patient’s already greatly disturbed speech. After the block of precentral gyrus had been cleanly and completely removed the exposed anterior surface of the postcentral gyrus which had been buried in the central fissure was stimulated. Stimulation of the more ventral part with a current of low voltage elicited flexion of the thumb; stimulation with a stronger current (12 volts) produced lateral deviation of the index finger and from a point located nearer the midline supination of the wrist.
On recovery from the operation there was no trace of the tremor. The right extremities were flaccid and completely paralyzed. Sensation was unchanged, but for a time her speech was worse because of the addition of some aphasis. This, fortunately, was quite temporary. Soon voluntary movement returned to the right arm and the entire lower extremity progressively became stronger. About six weeks after the operation voluntary movement first appeared in the right arm, but practically no voluntary movement ever returned to the fingers, hand, or wrist. At this same time a fine tremor returned to the right thumb. This gradually increased until a definite tremor-at-rest was constantly present in the thumb. This has continued ever since without much material change. There has also been some tremor of the right hand and wrist which is present only on movement of the right upper extremity. Her condition remained stationary and was the same when she was last seen, 14 months after the operation.

In my experience tremor, either at rest or in association with voluntary movement, has been abolished only when the representation of the affected extremity has been destroyed in the precentral gyrus. Sachs (1942) has noted that removal of the cortical tissue immediately anterior to the precentral gyrus, i.e., area 6, is not effective in relieving tremor. As a major part of the pyramidal tract arises from the precentral gyrus (area 4) while none is known to arise from area 6, this strongly suggests that tremor is mediated by impulses which descend via the pyramidal rather than the extrapyramidal fibres. However, this evidence is not conclusive as extrapyramidal fibres arise from both areas 4 and 6 and might be the ones concerned. Valuable additional evidence on this point is presented by the operations on the spinal cord in cases of tremor. Both Oldberg (1938) and Putnam (1938b) failed to affect the tremor of paralysis agitans by destruction of the anterior column of the spinal cord—a procedure which had had a very definite ameliorating effect in cases of choreo-athetosis. This would indicate that if tremor is produced by impulses travelling by way of the extrapyramidal systems the fibres involved must be different ones from those concerned in producing choreo-athetosis. Putnam (1940), and others who have followed his lead (Oliver, 1949; Ebin, 1949) have demonstrated that division of the lateral pyramidal tract in the spinal cord effectively reduces the tremor of parkinsonism. Thus it would seem quite conclusive that interruption of the pyramidal tract is essential to the abolition of tremor-at-rest except for some other observations which are as yet imperfectly understood. Browder (1948) has operated upon a considerable number of patients with paralysis agitans by dividing the anterior limb of the internal capsule. The tremor has been markedly reduced in most cases without the production of any considerable hemiparesis. According to Levin's (1936 and 1944) studies the fibres in the anterior limb of the internal capsule are connected with that portion of the frontal lobe anterior to the motor eye field (area 8) or what has been termed the prefrontal or frontal association areas. So far as is known all of the projection fibres of areas 4 and 6 pass downward in the posterior limb of the internal capsule.

Furthermore, there is no evidence that destruction of the cortex of the frontal lobe anterior to area 8 has any effect on tremor.* One cannot, therefore, be other than puzzled by Browder's (1948) observations. There are, however, two facts which are important in this connexion and which must not be lost sight of. To date there have been no published reports of postoperative examinations of the brains of any patients who have been operated upon in this fashion and in whom the tremor has been abolished. Furthermore, the division of the internal capsule, which is conducted under local anaesthesia, is continued posteriorly until there is a demonstrable "marked paresis" of the contralateral upper and lower extremities, and postoperatively there is a variable, though usually mild, interference with voluntary control of the upper extremity and the patient often walks with a slight limp. These facts would indicate that the exact nature and extent of the operative procedure on the internal capsule is as yet unknown. Browder feels that this operation should not be performed bilaterally because of undesirable effects.

Recently Walker (1949) and White (1950) have both reported a favourable effect upon parkinsonian tremor from section of the lateral segment of the cerebral peduncle. Walker has operated upon five patients in this manner and at least two have had considerable hemiparesis postoperatively. In White's single case there was no hemiparesis. Presumably the pyramidal tract was damaged little if at all in the more successful of these operations. Obviously, in Browder's operation the fronto-pontine tracts would suffer the greatest damage. (In the cerebral peduncle these pathways occupy the medial segment.) In Walker's and White's operations the parieto-pontine (temporo-pontine) fibres would be the ones divided.

* In this connexion I have observed one patient with a typical parkinsonian tremor-at-rest and a severe behavioural disturbance as the result of encephalitis. Because of the severity of the disturbance of behaviour a bilateral frontal lobotomy was performed on January 19, 1948, by a transection under direct vision of practically the entire white matter of both frontal lobes in the plane of the coronal suture. The effect upon the patient's behaviour has been most gratifying and permanent. Quite unexpectedly the tremor was in complete abeyance immediately after the operation. This continued for some time and then the tremor gradually began to reappear and within three months after the operation it was the same as it had been previously.
Naturally these plus our own observations on the effects of extirpation of the precentral gyrus create not a little confusion as to just which pathway is primarily concerned in the production of tremor-at-rest. Solution of this problem will, obviously, have to await further studies. In the meantime, however, the work of both Browder and Walker gives reason to hope that it may be possible eventually to abolish the tremor of parkinsonism without paralyzing the affected extremities.

Thus far we have stressed the effect of properly performed extirpations of the precentral motor cortex upon the abnormal involuntary movements of disorders of the extrapyramidal systems. It is equally important that we stress that all clinical investigations on this problem are still experimental, that the related problems are by no means solved, and that but few patients present a condition which is suitable for treatment in this manner. Cases of choreo-athetosis are suitable for cortical excision only when (1) the involuntary movements are sufficiently severe to be incapacitating either to the involved extremity or to the individual as a whole; (2) the involuntary movements are sufficiently severe so that both the patient and the physician agree that it would be worthwhile to take the usual risks of a craniotomy, with the possibility that convulsive seizures may follow the operation (present in about 10% of the cases and usually easily relieved by anti-convulsant drugs), and that the hemiparesis which is usually already present in these cases may be somewhat increased; (3) the involuntary movements are limited to one or both extremities on one side of the body.

The same qualifications apply to the selection of patients with tremor for operation. But in addition it must be further borne in mind that the operation will not favourably affect such other manifestations of the disease as the rigidity, the slowness of movement, the mask-like facies, the stooped posture and abnormal gait, the loss of associated movements and poverty of all movement, and the excessive salivation and the oculogyric crises which are found in many patients with tremor of the parkinsonian type. Likewise, the operation will not favourably influence the natural progress of the disease, and thus the condition in a patient with paralysis agitans limited to one arm will progress to involvement of the other extremities even though the tremor be abolished in the initially affected extremity by an operation upon the cerebral cortex. It is obvious, therefore, that abolition of the tremor of parkinsonism by removal of the appropriate part of the precentral gyrus is indicated only in those few cases where the tremor is limited to one side of the body and when the disease can be reasonably thought to have been arrested. Naturally, I have operated upon but few patients with tremor-at-rest. Those who have been operated upon have had their tremor as the result of cerebral trauma (when it is often associated with an even more violent intention tremor), or of a luetic menencephalitis in which the syphilitic infection has been rendered inactive by antiluetic therapy. Intention tremor is more often the result of some non-progressive condition, such as cerebral trauma, and is, therefore, more often suitable for such operative relief. I have not personally had any experience with the operations upon the cerebral peduncle (Walker) or the subcortical fibres in the precentral region (Meyers, Sweeney, and Schwidde, 1950) which have been performed in cases of hemiballismus, but welcome all information regarding these and other well considered, carefully planned and executed operations which shed any light upon the problems of pathogenesis, pathological physiology, and treatment of the extrapyramidal diseases which are characterized by abnormal involuntary movements. Only by the careful accumulation of information in this fashion will these problems ultimately be solved.

References


——— and Buchanan, D. N. (1932). Brain, 55, 479.


Also personal communications.


