ELECTRICAL ACTIVITY OF THE NEOSTRIATUM, PALEOSTRIATUM, AND NEIGHBOURING STRUCTURES IN PARKINSONISM AND HEMIBALLISMUS*

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The present investigation represents an extension of an inquiry into the electrical potentials of the basal ganglia and exposed cerebral cortex in Parkinsonism reported upon by one of us (R.M.) in 1941. At that time, the first recordings from the human caudate nucleus were obtained by means of an Adrian-Bronk needle inserted under direct inspection into the head of the nucleus and supported *in situ* by the operator's hand. The electro-caudatograms thus obtained were characterized by a faster frequency and lower amplitude than corresponding electrocorticograms recorded by means of concentric electrodes applied directly to various parts of the convexity of the frontal lobe. The relative crudity of these early attempts gave rise to the misgiving that the experimental findings might have been much more dependent upon the recording techniques employed than upon the pathophysiologic phenomena presumed to be under inquiry. Further exploration of the problem by more reliable techniques therefore appeared desirable.

Method

Before the institution of the experimental routine in each patient, all medication was discontinued for several days. Under local infiltration anaesthesia of the scalp with 1 per cent. procaine hydrochloride, paired burr openings were made through the right and left anterior vertical regions of the skull. The position of the opening on each side was so planned as to lie directly above the head of the caudate nucleus. The dura and pialachnoid were suitably incised and the scalp was closed in two layers with black silk. At a later time, usually within two hours of trepanation, a slender plastic shaft equipped with eight ring-type "pick-up" electrodes was passed through one of the burr openings. The direction given to the needle and its distance from the surface were such as to place the electrodes in one or more of the following subcortical structures in each subject: the head of the caudate nucleus, the putamen, crus II of the globus pallidus, the subcallosal bundle, the anterior portion of the body of the corpus callosum,

the substantia medullaris of the corona radiata, the olfactory area, the cortex of the olfactory sulcus, the hypothalamic area, and the infracallosal portion of the cingulate gyrus (Fig. 1).

The electrode shaft was of the same design as that recently employed by one of us (R.H.) collaborating with Belinson and Gibbs (Hayne and others, in the press) in a study of the electrical activity of the thalamus in epileptic patients. The length of the shaft was 10.5 cm. and its diameter 2.3 mm. Eight silver rings, each 2.5 mm. wide and separated by 3.0 mm. from its neighbours, served as pick-up electrodes. These were disposed along the distal half of the non-conducting plastic shaft. Within the shaft, an insulated wire coursed from each of the eight ring-type electrodes and emerged from the hub. To the free-hanging distal end of each wire a phone-tip jack capable of being plugged into the electrode junction box of a recording unit was attached.

Bipolar and monopolar recordings (the latter employing the ears as reference electrode) were made from both the standard electro-encephalogram scalp leads* and the subcortical leads in the corpus striatum by means of a Grass III-A, eight-channel ink-writing electro-encephalograph. In the earlier studies of the series, simultaneous recordings of the mathematically possible combinations of the scalp and subcortical leads were made. As the inquiry proceeded, it appeared warrantable to eliminate certain pick-up combinations from the schedule, so that only those which yielded the most characteristic and/or most useful localizing data were retained for subsequent experiments. Thus, in the case of the subcortical leads, bipolar combinations of (a) immediately neighbouring ring electrodes and (b) those removed from one another by a single intervening ring proved most practicable.

After the desired electrical recordings were obtained from the patient under study and while the electrode shaft was still *in situ*, pneumoencephalography was carried out. The purpose of the latter procedure was to help ascertain as accurately as possible, short of necropsy examination, the position occupied by each of the eight electrodes. The identification of the anatomical sites of the several electrodes was determined

* The "standard" placements of scalp leads are those attached to the left and right frontal, central, occipital, and temporal regions. These have been designated in the present paper by the abbreviations LF., RF., LP., RP., LO., RO., LT., and RT. The symbol "e" indicates that a monopolar technique was employed, the reference electrode being attached to the lobe of the ear.

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by the following means. A normal adult brain, freshly removed at autopsy, was suspended by a gauze hammock in 10 per cent. formalin solution until well hardened, and later sectioned through the mid-sagittal plane. The body and anterior horn of the right lateral ventricle were exposed to view by removal of the septum pellucidum and suitable portions of the fornix and corpus callosum. A "grid" consisting of a series of silk threads strung in parallel at intervals of 0.5 cm. was then superimposed upon the mesial surface of the right hemisphere in such fashion that its chords were approximately perpendicular to the antero-posterior axis of the hemisphere. The chord corresponding to the most rostral limit of the anterior horn was arbitrarily designated number 1. Succeeding chords were designated by the numbers 2, 3, 4, . . . 15. Each thread was regarded as the determinant of a separate coronal plane of the hemisphere. The brain was now suitably marked in correspondence with the determinants and was placed against a specially designed near-precision apparatus by means of which the indicated serial coronal sections were prepared at intervals of 0.5 cm. The coronal sections were identified by numbers corresponding to their respective chords and were separately photographed.

By comparing the position of the electrode shaft, as revealed in the lateral view of the patient's pneumoencephalogram, with a photograph of the grid-covered mesial aspect of the brain it was possible to determine with fair accuracy the chord (or chords) with which the axis of the electrode shaft most closely coincided. The photograph of the appropriate coronal plane was then compared with the axis of the electrode shaft and with the positions of the several ring-type electrodes as revealed in the antero-posterior view of the patient's pneumoencephalogram. On the basis of such data, the position of each of the eight ring-type electrodes was ascertained.

The ring-type electrode most distal to the hub of the shaft was arbitrarily designated number 1. The others, progressing in order toward the hub, were numbered 2, 3, 4, 5, 6, 7, and 8. Thus, for example, in the illustrations which follow 2-4 signifies that the bipolar technique was used and that the pick-up electrodes employed in obtaining the electrogram were the second and the fourth rings from the distal end of the shaft. Similarly, 3-e signifies that a monopolar technique was used and that the electrodes employed were the third from the distal end of the shaft and that attached to the ipsilateral ear.

It was possible in one instance to verify directly the structures through which the electrode shaft had passed. This was in patient A.L., a 42-year old housewife who died four days following operation for the relief of Parkinsonian tremors. She had undergone extirpation of the head of the caudate nucleus, section of fibres of the anterior limb of the internal capsule, and interruption of pallido-fugal fibres. Her postoperative course was generally satisfactory except for short-lived and irregular bouts of vomiting. In one of the latter

episodes she aspirated vomitus and died of asphyxia. Post-mortem examination confirmed that the electrode shafts used in two separate experiments on this patient had traversed the caudate nucleus and crus II of the globus pallidus (Fig. 2).

Experimental Group.—The subjects constituting the experimental group* dealt with in this paper consisted of eleven patients suffering from "extrapyramidal disorders." In nine of these, the diagnosis of Parkinsonism of either post-encephalitic or "idiopathic" varieties was made. The tenth patient had a chronic left hemiparesis and hemi-Parkinsonism consequent upon severe craniocerebral trauma. The eleventh was a 50-year old woman with moderately severe but well controlled diabetes who, ten weeks before the present study, suddenly developed a violent hemiballismus of the limbs of the left side. In each instance the experimental nature of the investigation was explained to the subject and full consent obtained for the study.

The plan of procedure consisted in recording electroencephalograms from the standard scalp leads and from the right and left subcortical structures of each patient. Since in all but two instances unilateral placement of the electrode shaft was employed, the procedure required as a routine two separate experiments upon each subject. In order to allow for clinical recovery from the effects of pneumoencephalography, therefore, several days were allowed to intervene between experiments. In all, twenty-one experiments were carried out on the experimental subjects: two on each of eight patients, one of each of two, and three on the remaining patient (see Table).

The recordings derived from each cerebral structure were separately analyzed with respect to (a) frequency, (b) voltage, and (c) relative polarity of waves. Those obtained from each subject were then compared with one another and also with those from all other subjects in both the control and experimental groups and an attempt was made to ascertain whether consistent relationships existed.

Results

Analysis of the electrical records derived from leads placed on the scalp, in the corpus striatum, and over the muscles of the extremities led to the following series of descriptions and tentative formulations.

Variations in Frequency.—Variations in the frequency of waves derived from mono- and bipolar scalp electrodes are, as is well known,

* Controls.—In addition to those of the experimental group, eleven control subjects, none of whom was considered to be suffering from "organic" disease of the brain, were studied in a manner similar to that employed for the experimental subjects. Seven of these were afflicted with intractable pain (pelvic carcinoma, phantom limb, etc.) and four with psychologic aberrations. All control subjects had been previously accepted for prefrontal lobotomy and studies of their cerebral action potentials were carried out several days prior to operation. The data referable to the control group have been made the basis of separate reports (Hayne and others, in the press; Meyers and Hayne, 1948). In the majority of instances the frequencies of waves recorded in the several control subjects were slightly lower than those generally encountered among "normals."

FIG. 1.—Pneumoencephalograms of patient L.P. The ventricles have been outlined with small dots for greater ease of identification. The configuration of the main structures encountered at the coronal plane traversed by the electrode shaft is similarly delineated.

Caud.=head of caudate nucleus ; A.L.=anterior limb of internal capsule ; Put.=putamen. The placement of the ring electrodes in this case was considered to be as follows : 1—putamen ; 2—anterior limb of internal capsule ; 3—margin of head of caudate nucleus and anterior limb of internal capsule ; 4 and 5—head of caudate nucleus ; 6—subcallosal bundle ; 7—corpus callosum ; 8—corona radiata, deep in hemisphere.

FIG. 2.—Horizontal sections of right hemisphere of patient A.L., illustrating tracts produced by electrode shafts. In A, arrow points to lesion in crus II of the globus pallidus. In B, arrow points to lesion in the head of the caudate nucleus.

encountered from subject to subject and from time to time within a given subject. Similar variations evidently prevail in respect of wave frequencies derived from leads located in the neostriatum, the paleostriatum, and their immediate neighbourhoods. The pertinent data is summarized in the Table, in which the *central tendencies** of the wave frequencies derived from the scalp electrodes have been arbitrarily arranged in ascending order. A comparison

of the central tendencies and ranges of wave frequencies in the control and experimental groups disclosed no significant disparities. In view of the familiar histologic and (presumed) functional derangements of the strio-pallidal apparatus in the so-called extrapyramidal diseases, this was a somewhat unexpected disclosure.

Relative Frequencies.—Reference to the Table and to Fig. 3 discloses that in any given subject the frequency of the bipolar subcortical waves exceeded by one to eight cycles per second that characteristic

* Ranges of means based on samples of one second's duration. A range is given in view of the fact that the frequencies and amplitudes varied from lead to lead as well as from subject to subject and from time to time within a given subject.

TABLE
CENTRAL TENDENCIES OF WAVE FREQUENCIES RECORDED IN EACH PATIENT FROM SCALP AND SUBCORTICAL ELECTRODES BY MONO- AND BIPOLAR TECHNIQUES

Patient	Sex	Age	Diagnosis	Tremor*	Rigidity*	Experiment No.	Scalp Leads	Subcortical Leads	
							Mono- and Bipolar	Mono-polar	Bipolar
A.G.	M.	52	Prksn.	+	+++	1	7 - 7½	7 - 8	10 - 12
						2	7 - 8	7½ - 8	10½ - 12
R.C.	M.	43	Prksn.	++	+++	1	7 - 8	7½ - 8	8 - 10
						2	7 - 8	8½ - 9½	10 - 12
W.G.	F.	38	Prksn.	(Lt.)		1	7½ - 8½	8 - 9	7 - 9
						2	8 - 9	8½ - 9	8 - 10
						3	8 - 9	8½ - 9	8 - 10
F.B.	F.	50	Hemibal.	+++ (Lt.)	0	1	7½ - 8½	8 - 8½	10½ - 11
A.L.	F.	42	Prksn.	+++	++	1	8 - 9½	8½ - 11	9½ - 11½
						2	8½ - 10	9½ - 11	9½ - 11½
E.G.	F.	65	Prksn.			1	8 - 9	8 - 9½	15 - 17
						2	8½ - 9½	None recorded	16 - 17
L.P.	M.	47	Prksn.	++ (Rt.)	++	1	8 - 9½	8½ - 9½	9½ - 10½
L.D.	M.	29	Hemi-Prksn. (trauma)	+++ (Lt.)	++++ (Lt.)	1	8 - 9	8 - 9	11 - 12
						2	8½ - 9	8 - 9½	11 - 13
W.H.	M.	36	Prksn.	+	++++	1	8½ - 9	8 - 9	11 - 12
						2	8½ - 9	11 - 12	12 - 14
C.H.	M.	48	Prksn.	++++	+++	1	9 - 9½	8½ - 9	10 - 11
						2	9 - 9½	8½ - 10	11½ - 14
W.B.	M.	42	Prksn.	++++	+++	1	9½ - 10½	9 - 10	8 - 10
						2	9½ - 10½	9½ - 10½	9½ - 12

* Unless designated by (Rt) or (Lt), the disorder may be presumed to have obtained bilaterally. Tremor and rigidity are here estimated as if on a continuum, ranging from one plus (slight) to four plus (very marked).

of waves derived from scalp leads, regardless of whether obtained by the mono- or bipolar techniques. In addition, those experimental subjects exhibiting a relatively low frequency of waves derived from the scalp leads (for example, 7-8 per second) exhibited in the concomitantly-recorded subcortical waves obtained by the bipolar technique a frequency relatively slower than that of the corresponding subcortical waves obtained in their fellow-subjects. All these data were virtually the same as those derived from the control cases.

Amplitude.—The amplitude of waves obtained from the scalp electrodes varied from subject to subject and from time to time within each subject. The over-all *central tendency*, 35-75 μV , corresponded closely to that encountered in control subjects when comparable recording techniques were employed. Similar variations from subject to subject and from time to time within a given subject prevailed in respect to the wave amplitudes obtained by the bipolar technique from electrodes

located in the neo- and paleo-striatum and their neighbouring tissues. The over-all *central tendency* of the amplitude of such subcortical waves obtained by the bipolar technique approximated 15-25 μV . This observation conformed closely to that demonstrated in control subjects when similar recording techniques were used. Thus, the ratio of the amplitude of subcortical waves obtained by the bipolar technique to that of waves derived from the scalp by either the mono- or bipolar technique varied as 1:2 to 1:3. In but one case, that of L.D., the ratio was as 1:1 (Fig. 3).

The amplitude of the waves derived from bipolar subcortical leads appeared to vary with the quantity of tissue between pick-up electrodes. Thus, the amplitude of electro-encephalograms recorded from between adjacent rings exhibited a central tendency of 5-30 μV , while that from between rings separated by an intermediate ring exhibited a central tendency of 20-35 μV . All these data closely resembled those demonstrable in control subjects and suggested that the recorded differences in amplitude *may be* less a

FIG. 3.—Electro-encephalograms of patient W.H., illustrating that the *frequency* of waves derived by bipolar technique from pick-up leads located in the region of the corpus striatum (2-4, 4-6, and 6-8) is higher than that of waves derived by monopolar technique; (a) from leads in the region of the corpus striatum connected to the ear as reference electrode (2-e, 4-e, 6-e, 8-e); and (b) from scalp lead(s) similarly connected (RO-e). This record also illustrates that the *amplitude* of waves derived by the bipolar technique from leads in the striatal region is perceptibly less than that of waves derived by the monopolar technique from the striatal leads and by the mono- and bipolar techniques from the scalp leads. M. Art.=muscle artefact.

function of the electrophysiologic dynamics of the tissues under inquiry than of the recording techniques employed. The issues cannot be resolved within the scope of this paper. The necessity for further study of the matter is indicated.

Temporal Relationships and Variations in Wave Form.—In general, the frequency and amplitude of

waves derived from subcortical leads connected to the ear as reference electrode corresponded much more closely to the wave phenomena derived from mono- and bipolar scalp leads than to those derived from bipolar subcortical leads. Indeed, they were scarcely distinguishable from those obtained from the scalp leads. The non-correspondence which actually exists between the (mono-polar)

FIG. 4.—Electro-encephalograms of patient W.H., recorded by the monopolar technique; (a) from scalp leads to ear electrode (LF-e, RF-e, LP-e, RP-e, LO-e, and RO-e); and (b) from leads in the striatal region to ear (1-e, 2-e, 3-e, 4-e, 5-e, and 6-e). The close similarity in frequency and amplitude of the waves obtained from both sources is apparent from inspection. Although not illustrated here, waves derived by the bipolar technique from scalp leads closely resemble in frequency and amplitude all the recordings shown above.

sub-cortical electrograms and those derived from the scalp leads can best be demonstrated in consideration of their temporal relationships and variations in wave form (Fig. 4).

Two inferences appear warranted by these observations. The first is that waves derived from subcortical structures connected to the ears as

reference electrode appear to reflect to a far greater degree the activity of cerebral tissues *between* the subcortical structure in which the ring-type electrode is located and the ears than they do the activity of the subcortical structure itself. This formulation is generally supported by all subcortical records obtained from both the experimental and control

FIG. 5.—Electro-encephalograms of patient C.H., illustrating simultaneous monopolar recordings of electrical activity from the left (Lt 2-e and Lt 4-e) and right (Rt 2-e and Rt 4-e) neostriatal regions. These "twin" recordings from corresponding structures of the opposite sides are highly similar in frequency, amplitude, form, and polarity. The observation supports the view that monopolar recordings employing the ear as reference electrode reflect the activity of the adjacent temporal cortex to a greater degree than they do that of the striatal structures in which the ring-type electrode is located.

FIG. 6.—Electro-encephalograms of patient L.P., obtained by the bipolar technique from the neostriatum and neighbouring structures (compare with Fig. 1). The recordings demonstrate that waves derived from a circumscribed region, in this case the superior half of the head of the caudate nucleus (4-5 and 5-6), exhibit an electrical sign opposite that of waves from neighbouring tissues. Such a circumscribed region appears to act as a relatively constant source of electrical discharge and to impose upon circumferential tissues a reciprocal polarity.

⊖ = electronegativity ; ⊕ = electropositivity.

groups, but is particularly well illustrated in tracings simultaneously obtained from the right and left caudate nucleus of patient C.H. (Fig. 5). It will be noted that the electro-encephalograms thus obtained appear to be almost identical with one another. Evidently the frequency and amplitude of waves derived from tissues immediately surrounding the subcortical electrodes may be considerably "masked" by the electrical activity of cerebral tissues interposed between the deep-lying structures and the ear, notably the cortex of the temporal lobe.

The second inference that may be drawn is that an autochthonous electrical activity appears to be generated by the corpus striatum as well as by the cortex and that each of these foci of activity tends to exert electrical potential effects upon its own neighbourhood. There is no evidence at hand to indicate that under ordinary physiological conditions the one may be "submerged" by the other.

Fast Waves.—As in the control subjects, short-lived bursts of moderately fast (13–20 per second) waves characterized by a low-to-average voltage interrupted at irregular intervals the slower frequency phenomena generally prevailing in the subcortical leads. Such bursts were observed in electro-encephalograms derived from all subcortical leads in all subjects. With rare exceptions, their duration was less than one-half second and in no case was it found to exceed one second (Hayne and others, to be published).

Sites Explored.—No consistent differences in respect to frequency, amplitude and wave-form could be demonstrated among the several subcortical nuclei and neural tracts explored by the technique here employed. By and large, the recordings from the globus pallidus, putamen, head of the caudate nucleus, anterior limb of the internal capsule, subcallosal bundle, etc., displayed non-

disparate electrical characteristics, as determined by analysis of their frequency, amplitude, and wave-form.

Reciprocal Polarity.—Analysis of the polarity of waves derived from the several subcortical structures suggested that a relatively constant "source" (or sources) of electrical discharge exists within circumscribed portions of the neostriatum. Such a "source" appeared to impose upon circumferential tissues a reciprocal polarity (Fig. 6).

In addition, the phenomena of (a) slight "shift of the discharging focus" and (b) "fluctuation of polarity" of the neighbouring tissues previously encountered in the control group had their counterparts in the experimental group. This observation accords with that of Adrian and Yamagiwa (1935) and Adrian (1936) in their delineation of the source of the occipital alpha rhythm. The latter "focus," like the foci demonstrated in the present study, appeared to be slightly variable, expanding, contracting, and wandering to and fro within a narrowly defined range.

"Fast Runs" in Parkinsonism.—In the bipolar subcortical tracings of five of the Parkinsonian cases (E.G., C.H., A.L., W.H., and W.B.) "fast runs" were frequently observed. These exhibited a wave frequency of 17–23 per second and a duration of from two to six seconds. Their amplitude was generally of the same magnitude as that of the prevailing ("dominant") waves of the electrogram under examination (Fig. 7). An attempt to discover a correlation between the presence or absence of these fast runs and the degree of tremor and rigidity exhibited by the patient (see Table) was unsuccessful. The non-appearance of fast runs in the remaining five cases of the Parkinsonian group would seem to warrant the conviction that such runs do not constitute a uniformly demonstrable characteristic of the subcortical electrical potentials in Parkinsonism.

FIG. 7.—Electro-encephalograms from the striatal region of patient W.H., illustrating a "fast run" of 19-per-second waves having a duration of approximately 6 seconds and an amplitude approximately equal to that of the generally prevailing waves. The latter may be seen at the right and left extremes of the recordings. Such fast runs occurred irregularly in five of the ten Parkinsonian cases of this series. None of the control cases exhibited runs of this character.

A tenable explanation of these findings does not appear capable of formulation at present.

Slow Waves in One Patient.—In one Parkinsonian patient, W.B., the most conspicuous feature of the bipolar subcortical tracings was a slow ($5\frac{1}{2}$ per second) wave frequency of average amplitude. This phenomenon was apparent only in those waves derived from the tissues of a well circumscribed portion of the caudate nucleus (Fig. 8). The concomitantly-recorded electromyograms in this patient exhibited from time to time abnormal rhythmic oscillations, the rate of which (4 per second) was perceptibly slower than that of the electrocaudatograms ($5\frac{1}{2}$ per second). It appears unlikely, therefore, that the motor impulses delivered to the muscles were mediated in any *direct* fashion by electrical impulses from the caudate nucleus. Further evidence of the *lack* of correlation in this patient between the electrical activity of the caudate nucleus and that of the contralateral somatic muscles arose from the observation that the *electrocaudatographic recordings were unaltered by the appearance and disappearance of abnormal electromyographic oscillations* and from the further

observation that *significant alterations of the electrocaudatograms corresponding to the appearance and disappearance of clinically observable tremors were not demonstrable*.

Correlation with Clinical Findings.—No correlation was apparent between the frequency, amplitude, and form of waves derived from the scalp and subcortical electrodes on the one hand and the clinically estimated degree of tremor and/or rigidity manifest in the patients suffering from Parkinsonism on the other (see Table). Nor was any correlation demonstrable when the electromyograms obtained from the affected limbs of these patients were compared with simultaneously-recorded scalp and subcortical electrical potentials (Fig. 9).

Hemiballismus.—The electrograms obtained from the single case of hemiballismus in the present series appeared to be similar in all respects to those obtained from subjects of the control series. This again was an unexpected finding.

Discussion

Impressed with the generally disappointing results of conservative therapeutic measures in the

FIG. 8.—Electromyogram (Emg., left leg) and concomitantly recorded electro-encephalograms and electrostriatograms of patient W.B., illustrating (2-4 and 4-5) the slow ($5\frac{1}{2}$ per second) frequency of prevailing waves derived from the right caudate nucleus. The wave rate in this subject was unique among the subjects of the experimental and control groups. During the recording of the brain waves here illustrated, the electromyogram was quiescent, the tremors in the left lower limb having 'spontaneously' subsided for the moment (Compare with Fig. 9). Bl=eyeblick. Muscle artefacts may be seen imposed upon the electro-encephalograms from leads LF-e and RF-e.

FIG. 9.—Electromyogram (Emg., left leg) and simultaneously recorded electro-encephalograms and electrostriatograms of patient W.B., illustrating the gradual reappearance of tremors (upper record) and full-blown presence of tremors (lower record). The frequency of the electro-tremograms is consistently 4 per second. The electrostriatograms recorded by mono- and bipolar methods are apparently unaltered, irrespective of the spontaneous ebb and flow of tremors (compare with Fig. 8).

treatment of Parkinsonism, several investigators* endeavoured during the years 1930-42 to devise central neurosurgical procedures which might ameliorate tremors, rigidity, and the related incapacitating symptoms of the disorder. The first of these attempts, that carried out by Puusepp (1930) and repeated by Rizzatti and Moreno (1936) consisted in surgical section of the column of Burdach in the cervical cord. This failed to achieve its purpose. Shortly afterward, Putnam (1938b), pursuing the attack upon spinal cord mechanisms, reported disappointment in section of the antero-lateral funiculus at high cervical levels. Interruption of the crossed pyramidal tract, however, was followed for some months by substantial improvement (Putnam, 1938a, b, 1940a, b). In 1939, Bucy and Case reported their experience with a cerebral approach, extirpating portions of the motor and premotor cortices. Subsequently, the cortical attack was more intensively pursued by Bucy (1944), Putnam, White, and Klemme (1940). The evidence obtained by these workers appeared capable of general formulation somewhat as follows: the abolition of tremor requires the surgical destruction of the precentral cortical projections of the affected limb(s), notably, Brodmann's areas 4 and portions of 6-a. The inevitable consequence of the operation is a spastic paresis of the limb(s) with tendon hyper-reflexia and enduring dyspraxia. Bucy's (1944, 1948) critical evaluations led him to assert that the procedure was warranted only in patients already severely disabled by Parkinsonism. He added that, in view of the functional deficits above enumerated, bilateral operation was not justifiable.

One of us (R.M.) experimented with extirpations and sections of several structures at the level of the basal ganglia. The findings encountered in the first twelve cases were reported upon in 1941 and 1942. This line of experiment has been resumed since the conclusion of the 1939-45 war, and the data will be reported in a later communication. The attack on the deep-lying structures has been further pursued by Browder (1948) in sectioning fibres of the anterior limb of the internal capsule back as far as the genu. The most recent procedure, carried out by Wyke (personal communication) in thirty-six cases, renews the attack at the cortical level. In Wyke's procedure a simple incision running parallel and just rostral to the suppressor strip (area 4-s) is made through the cortex and subcortical U-fibres, thus separating the more direct

cortico-cortical connexions between areas 4 and 6 (McCulloch, 1944).

With regard to the several surgical procedures—pyramidal, cortical, subcortical, and basal ganglionic—referred to above, some highly encouraging results have been realized in some instances and disappointing results in others. The slowly-accumulating factual data has permitted the tentative formulation of pathophysiologic concepts (Bucy, 1944; Meyers, 1941) bearing upon the hyperkinetic disorders. These are at present in process of evaluation.

Of the several experiments carried out at the level of the basal ganglia, that of pallidofugal section appeared to be the most promising in the sense that, when effective, the patient's tremors were virtually abolished, his rigidity phenomena perceptibly diminished, and the various clinical disabilities consequent upon poverty of movement substantially improved. Highly important was the observation that the patient did not suffer further embarrassment of motor, co-ordinative, eupractic, and speech functions such as those frequently described as the sequelæ of cortical extirpations and interruptions of the crossed pyramidal tract at the cervical cord levels. Unfortunately, some failures were encountered with the pallidofugal procedure as with all other procedures. These failures necessarily called for speculation as to the underlying reasons. One obvious suggestion was that the operative procedure itself had not been performed with equal precision in each case. While evidence was not (and even now is not) such as to permit dismissal of this account, the operator felt that a fair standardization of procedure had been worked out in regard to pallidofugal section and that other theoretical accounts merited exploration. In 1941 an alternative notion was tentatively proposed (Meyers, 1941) which depended for its support upon two thought-provoking circumstances: (a) the highly contradictory character of apparently reliable histopathologic studies in Parkinsonian and non-Parkinsonian cases; and (b) the disparate results obtained in connexion with each of the various surgical procedures. In effect, this hypothesis suggested that Parkinsonism might profitably be regarded as a *clinical manifestation* rather than as a "disease entity" and that, from the *pathophysiologic* point of view, it might well turn out that multiple (as opposed to unit-factor) neural mechanisms subtend the disorder. It seemed reasonable to suppose that one or more of the postulated mechanisms might indeed be common to all cases, but that this circumstance in no way impelled the conviction that all mechanisms are identical in all cases presenting similar clinical findings. If, as hypothesized, the

* Browder, 1948; Bucy and Case, 1939; Bucy, 1944, 1948; Delmas-Marsalet and Van Bogaert, 1935; Foerster and Gagel, 1932; Klemme, 1940; Machanskij, 1935; Meyers, 1940, 1941, 1942a and b; Oldberg, 1938; Putnam, 1933, 1938a and b, 1940a and b; Puusepp, 1930; Rizzatti and Moreno, 1936.

neural loops functionally usurped in some cases differed from those usurped in others, the result obtained by a given operative procedure would clearly depend upon whether the usurped loop, as an integral part of the tremor-producing complex, had or had not been surgically interrupted.

If, then, the notion of pathophysiologically different kinds of Parkinsonism may tentatively be entertained, it manifestly becomes a matter of practical importance for the clinical investigator to decide *pre-operatively* whether a candidate is likely to derive benefit from surgery. And, assuming the answer to be in the affirmative, it becomes equally important for him to decide which of several possible operative procedures appears most applicable to the case in hand.

It was with the hope that some light might be thrown upon these matters that the present study was projected. The results unfortunately do not permit a resolution of the relevant issues. They do, however, appear to lend some support to the hypothesis that the subtending pathogenetic processes may indeed differ somewhat from case to case. This inference is suggested by (a) the peculiar "fast runs" encountered in five of the ten Parkinsonian subjects, (b) their absence in the remainder, and (c) the singularly slow frequency encountered in the electroencephalogram of patient W.B. No comparable recordings were seen in the eleven control subjects. That such electrographic differences do exist is inescapable. Their clinical significance remains to be elucidated.

Summary

1. Electrograms were recorded from the neo- and paleostriata and their neighbourhood in ten cases of Parkinsonism and one of hemiballismus. The wave characteristics of frequency, amplitude, form, and polarity were compared with (a) the corresponding phenomena of concurrently-recorded electroencephalograms obtained from standard scalp leads and (b) electromyograms of the tremor-affected limbs. All data derived from the experimental group (here reported upon) were evaluated in view of data and interpretations derived from eleven control subjects (elsewhere reported upon). Twenty-one experiments were performed upon the experimental group and eleven upon the controls.

2. The frequency of waves derived by the bipolar technique from the several structures of the corpus striatum and neighbourhood varied from individual to individual and from time to time within each individual. The rate of electrograms recorded (by the bipolar method) exceeded that of electrograms derived from the scalp leads (by both the bipolar and monopolar methods) by one to several cycles

per second. Similar observations were made among the control subjects.

Short-lived bursts of moderately fast frequency (13–20 per second), having a duration of 0.5–1.0 seconds and a low to average voltage interrupted at irregular intervals the slower frequency, higher amplitude waves generally predominating in recordings from leads placed in the corpus striatum. Such were observed in the electrostriatograms of all subjects in both the control and experimental groups.

3. The amplitude of electrostriatograms obtained by the bipolar technique varied from individual to individual and from time to time within each individual, approximating 14–25 μ v. This was of smaller magnitude than that of electroencephalograms concomitantly recorded by mono- and bipolar techniques from the standard scalp leads, the ratio being as 1 : 2 to 1 : 3.

Evidence at hand suggests that the differences in amplitude between electrostriatograms and electroencephalograms depends upon the smaller quantity of tissue between pick-up electrodes in the former (as compared with the latter), rather than upon the electrophysiologic properties of the cerebral tissues themselves. The findings relevant to amplitude were similar for both the control and experimental groups.

4. Whether electrograms were derived from scalp ear or striatum-ear leads (that is, by the monopolar technique), the frequency and amplitude of the waves were very similar. This similitude probably arises from the proximity of active cortical tissue of the temporal lobe to the electrode attached to the ear. The non-correspondence which genuinely exists between the electrograms from the two mentioned sources was demonstrable in terms of their disparate temporal relationships and variations in wave form. The phenomena were obtained in the controls as well as in the experimental group.

5. Electrograms derived from the several deep lying structures explored (for example, caudate nucleus, putamen, globus pallidus, subcallosal bundle, etc.) exhibited no features by which one structure might be distinguished from its fellows. This observation held among both the experimental and control subjects.

6. Analysis of the phenomena of wave polarity and reversal of electrical sign of the electrostriatograms strongly suggested that a relatively constant circumscribed source(s) of electrical discharge obtains within the head of the corpus striatum and/or the putamen. Such a region was almost continuously possessed of an electrical sign opposite to that of the surrounding zones. Similar findings obtained among the control subjects.

7. The bipolar electro-encephalograms derived from the corpus striatum of four among the ten cases of Parkinsonism exhibited no features by which they could be distinguished from the comparable electro-encephalograms of control subjects. Of the six remaining cases, however, five exhibited "fast" runs (rate, 17–23 per second; duration, 2–6 seconds; and amplitude comparable to that of the prevailing waves of the record). Such runs frequently interrupted the slower-frequency phenomena generally characteristic of the subject's record. The sixth case, on the other hand, exhibited a singularly slow rate of dominant waves ($5\frac{1}{2}$ per second). The source of the latter appeared to be a well circumscribed region in the dorsal half of the caudate nucleus. The phenomena observed in these six cases had no counterpart among the control subjects. It was not possible to identify a consistent relationship between (a) the type of electrostriatogram derived from a given subject and (b) the kind and degree of clinical features of Parkinsonism exhibited by him.

8. No relation was apparent between (a) the electrical activity of the corpus striatum and neighbouring structures and (b) the presence or absence of electromyographic activity and clinically observable alternating tremors. Moreover, when electromyograms corresponding to tremor activity were recorded, their frequencies (4–5 per second) did not correspond to those of the concomitantly-recorded electrostriatograms and electro-encephalograms.

9. The electro-encephalograms obtained from the one case of hemiballismus in the experimental group did not differ greatly from those of eleven control subjects.

10. The findings lend support to the hypothesis that, from the pathophysiologic point of view, Parkinsonism may differ from case to case in regard to the neural loops usurped. A multiordinal concept of the neural mechanisms involved in the production of tremors and rigidity is suggested, in contradistinction to a unit-factor process (for example, "disease" of the substantia nigra) such

as has traditionally been sought in histopathologic terms.

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