Campotomy in Various Extrapyramidal Disorders


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In 1950 we observed a 74-year-old patient suffering from hemiballismus that was relieved by a mesencephalic lesion. The patient died 5 weeks postoperatively of bronchopneumonia and renal failure. Macroscopically a lesion was found that extended from the tegmentum of the midbrain lateral to the nucleus ruber into the substantia nigra, as illustrated in Part I of Stereencephalotomy. The histological examination revealed that the lesion produced by us affected the medial part of the substantia nigra and interrupted the mesencephalic part of Forel's field H (Fig. 1). In view of the fact that a major portion of the pallidofugal fibers can be interrupted in Forel's field H by a relatively small lesion, it seemed of interest to study the effect of lesions restricted as far as possible to Forel's field H (campotomy) upon parkinsonian tremor, rigidity, and other so-called extra-pyramidal disorders. The possible importance of this area in the mechanism of tremor was demonstrated by experiments in which it was observed that stimulation of this field, similarly to that of the pallidum, is able to increase a tremor induced by stimulation of the mesencephalic tegmentum (Fig. 2). The report by Strassburger and French also showed that in cats tremor induced by Serpasil could be eliminated by lesions including Forel's field H2. Meyers, who concentrated his efforts upon the substantia nigra several years after publication of our observation mentioned above, seemed to have lost some of his enthusiasm for nigral lesions and to have shifted his interest to the fields H, H1 and H2. A brief account of our initial observations on campotomy appeared in the Transactions of the American Neurological Association.

In the present series of patients with extrapyramidal disorders, the lesion was first produced in the mesencephalic part of field H, dorsolateral to the nucleus ruber and ventrolateral to the tegmental area from which we had attempted to influence tremor and rigidity in parkinsonian patients in a previous study. In the course of this work it was found that lesions in the thalamic part of field H are more efficient than those in the mesencephalic part so that in the later phase of our work we produced the lesion anterior and lateral to the nucleus ruber. Lesions of the zona incerta including fields H1 and H2 were not performed in order to avoid injury to the corpus subthalamicum and the danger of producing hemiballismus.

The following fiber systems form, or pass through, Forel's field (Fig. 3):

1. Pallidofugal fibers end partly in the nucleus campi Foreli that sends the prerubral tract to the nucleus ruber; partly the pallidofugal fibers by-pass the nucleus campi Foreli and end in the nucleus ruber, and possibly also in other cell groups of the mesencephalic tegmentum; into the latter degenerating fibers could be traced from lesions in Forel's field. The latter studies suggested that fibers from the ventral thalamus terminate in the reticular formation dorsal to the magnocellular part of the ruber. Martinez also found fibers from the pallidum to the prerubral tegmentum and to the ruber.

2. Rubrothalamic fibers and cerebellothalamic fibers end chiefly in the nucleus ventralis lateralis thalami from where impulses may be continued to the motor and

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Fro. 1. Lesion (L) of mesencephalic part of Forel's field H and of substantia nigra in a patient relieved from hemiballismus. H = Forel's field; N = substantia nigra on normal side; S = old softening.

premotor region as well as to the globus pallidus. There also may exist direct rubro- and cerebellopallidal fibers. Johnson and Clemente traced from the tegmentum of the midbrain many fibers to the ventrolateral nucleus and a few fibers to the ipsilateral pallidum internum.

3. Corticofugal fibers carry impulses from the motor cortex to the prerubral field; there are also fibers from the prerolandic area to the ruber, from the Sylvian and Rolando opercula to the ruber, and from the superior temporal gyrus, perhaps also from the parietal lobe, to the ruber. Part of these fibers also may reach other cell groups in the tegmentum of the midbrain. The corticofugal fibers from the occipital lobe apparently are located more dorsally. Fibers leaving the pedunculus cerebri, stimulation of which elicits conjugate movements of the eyes (in the cat particularly upward, to the opposite side and rotation), also traverse this area.

4. Some hypothalamofugal fibers ascend anterior to the nucleus ruber, particularly the dorsal hypothalamotegmental tract that connects the ventromedial hypothalamic nucleus and the posterior hypothalamic area with the nucleus mesencephalicus profundus pars dorsalis. Close to the medial aspect of Forel's field, one finds the mammillotegmental tract that ends in the dorsal tegmental nucleus; by way of the latter nucleus impulses may be transmitted from the mammillary bodies to the dorsal longitudinal fasciculus of Schütz.

Fig. 2. Tremor in the left (L.F) and right foreleg (R.F) induced in a cat by stimulation of the left reticular formation. Additional stimulation of left Forel's field (L. Forel) increases the amplitude of the right-sided tremor. (Experiment was described previously but not illustrated.)

Fig. 3. Fiber systems forming, or passing through, Forel's field H.

B.c. = brachium conjunctivum
CM = centrum medianum
Co = cerebral cortex
H, H1, H2 = Forel's fields
Hy = hypothalamus
Ma = mammillary body
NeF = nucleus campi Foreli
Pa = pallidum
Pe = cerebral peduncle
R = red nucleus
Re = reticular formation
VL = nucleus ventralis lateralis thalami
5. From the tegmentum of the rhombencephalon and mesencephalon fibers could be traced that pass through Forel's field and are apparently part of the system ascending from the reticular formation.

Stimulation of this region was performed routinely before lesions were produced in order to test the position of the electrode and to avoid proximity to the corticospinal pathway ventrally, the sensory thalamic-relay nuclei dorsally and the third nucleus posteriorly.

On rhythmic bipolar stimulation and sometimes also on closing of the D.C. applied for production of lesions, various effects could be observed that will be described in more detail in another publication and will be summarized here only briefly.

1. Increase in the amplitude and/or frequency of an existing contralateral (occasionally also of a homolateral) parkinsonian tremor or production of a previously latent tremor (Fig. 4) could be observed in about one-half of the patients ( pulses ~10 msec. in duration at a frequency of 20–30/sec., up to 8 V. measured on an oscilloscope). Decrease or depression of such a tremor (Fig. 5) was observed chiefly with higher frequencies (100/sec.); however, it has to be emphasized that such high-frequency stimulation may also increase the tremor or may elicit a previously latent tremor. Conversely occasionally it was observed that low-frequency stimulation or D.C. were able to inhibit the tremor. In rare instances opposite effects appeared in the left and right extremities, e.g. increase of tremor on the side contralateral to the stimulation and depression on the homolateral side, or vice versa. Alteration of the tremor by stimulation of this area also has been observed by French et al. and by Obrador.

2. Occasionally there was an increase of existing athetotic movements.

3. There appeared conjugate movements of the eyes in vertical directions (upward or downward) and/or horizontal movements to the opposite side. The combination of such ocular movements may result in oblique movements of the eyes or oblique nystagmus.

4. Movement of the homolateral eye was induced; it usually was directed inwardly.

5. Vegetative effects, chiefly upon the contralateral vasomotor nerves, were elic-
Production of Lesions

Eventually the following method has been devised:

After visualization of the 3rd ventricle with Pantopaque, the sheath of the electrode is introduced perpendicular to the intercommissural line, 11 mm. anterior to the posterior commissure for a length of the intercommissural line of 25–27 mm. (Fig. 6). For a shorter intercommissural distance (23–24 mm.) the lesion is placed 10 mm. anterior and for a longer intercommissural distance (28–29 mm.) 12 mm. in front of the posterior commissure. The puncture canal reaches the level of the intercommissural line 6–7 mm. lateral from the median plane.

In order to avoid the sagittal sinus, the puncture canal is directed ventromedially at an angle of 5° to the median plane. Under these conditions, puncture canals, 60, 70 or 80 mm. long, should enter the dorsal surface of the brain 12 mm., 12.5 mm., or 13 mm. lateral to the midline to reach a point 6 mm. lateral at the horizontal level of the intercommissural line. For production of the lesion in front of the nucleus ruber the stylet of the electrode initially was directed medialward. However, in view of the appearance of paresis of single muscles of the eye in some instances, the stylet is now directed anteromedialward, and a length of 2 mm. is chosen for production of the lesion.* In order to produce lesions at the lateral border of the nucleus ruber, the stylet (3 mm. in length) is directed posterolaterally since the lateral border of the ruber extends more lateralward in posterior levels because of the increase of the diameter of the nucleus ruber (Fig. 7). The tip of the sheath from which the stylet protrudes is placed in the following levels: +2 mm., 0 (level of the intercommissural line), −2 mm. and, if necessary, −4 mm. Fractionated anodal electrolysis as described in the monograph on stereoelectrocoagulation of the thalamus made use of with periodic dynamometric control of voluntary contractions of muscles of the hand.

All patients except those with severe athetosis were operated upon under local anesthesia in order to observe the effect of the procedure upon the involuntary movements and upon the strength of the voluntary contractions. They were sedated with phenobarbital (100 mg.) and atropine sulfate (0.6 mg.). Nitrous-oxide-ether and Fluothane anesthesia was applied in cases of severe athetosis.

Material

There were 25 parkinsonian patients in this series, 12 males and 13 females; 6 cases were postencephalitic, 18 idiopathic, and 1 was of post-traumatic origin. The patients ranged in age from 30 to 74 years, and the duration of the disease from 2 to 15 years. The postoperative duration of observation following the camptotomy lasted from a few weeks to 2 years.

Twenty-five of these patients had the typical tremor at rest; 20 had rigidity of varying degree.

Results

The effect of the lesions of field H upon the tremor and rigidity of these parkinsonian patients is summarized in Table 1. This effect was more pronounced following lesions of the thalamic part of field H in front of and lateral

* For the same reason we puncture now 1 mm. more anteriorly (11 to 13 mm. in front of the posterior commissure).
to the nucleus ruber than following lesions in the mesencephalic part. Fig. 8 illustrates the postoperative changes in the electromyogram.

In 1 of these patients, the simple mechanical effect of introducing the electrode into the nucleus ruber was sufficient to stop the tremor of the contralateral arm and hand, at least transitorily. The lesion of Forel's field was postponed purposely in order to follow up the effect of this puncture; it was added after the tremor reappeared, but with smaller amplitude, 4 days after the puncture.

The differences in resistance to passive movements before and after campotomy could be demonstrated objectively with the previously described myotonometer (Fig. 9). Recently we also have used for measurement of the resistance to passive movements a special dynamometer that permits estimation of the passive resistance in all joints of the extremities. It should be emphasized that decrease of the rigidity does not necessarily improve an existing slowness of movements. Although the effect upon tremor and rigidity as a rule is noticed in the opposite extremities, a somewhat weaker, but definite, effect upon the homolateral side could be observed in 2 cases. In 2 other patients, the decrease or abolition of the contralateral tremor was associated with an increase of this phenomenon on the homolateral side. It may be recalled that occasionally opposite effects on the homo- and contralateral extremities also were observed on stimulation.

In a patient with posthemiplegic tremor (Table 2) the decrease of the tremor was only transitory. A definite, more lasting effect (duration of observation 6 months) was observed in a patient with circumscribed myoclonia.

R.M., a 19-year-old white male, was admitted to Temple University Hospital on April 23, 1962

**TABLE 1**

Effects of campotomy upon parkinsonian tremor and rigor

<table>
<thead>
<tr>
<th>Definitely Reduced or Abolished</th>
<th>Moderately Reduced</th>
<th>Uninfluenced</th>
<th>Recurred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tremor</td>
<td>15</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>25 cases</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rigor</td>
<td>16</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>20 cases</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
with a history of having recovered from an attack of spinal meningitis at the age of 6. At the age of 11, he began to have involuntary "woofing" noises from the throat. The involuntary grunting noises progressively became worse and were associated with myoclonic movements affecting the left shoulder, arm and left diaphragm. There also appeared myoclonic jerks of the abdominal muscles on the left side which appeared synchronously with his abnormal vocalization. The movements ceased during sleep and were less pronounced when he was relaxed. When the movements were severe, the head would jerk backward because of myoclonic movements of the posterior cervical muscles.

The objective neurological findings otherwise were normal. The operation had to be postponed because of a local infection.

On Sept. 27, 1962, under local anesthesia, a right campotomy was performed.

Following the operation there was a marked reduction in the abnormal movements described above. The head was held normal, without jerking, and there was a marked decrease in the intensity and frequency of the myoclonic movements of the left shoulder and arm (Fig. 10). The disturbing loud grunting noises had subsided almost completely. He returned to his former occupation as a leather worker and has been employed gainfully (duration of observation 12 months after operation).

A definite influence of campotomy upon athetotic movements of patients with cerebral palsy was observed in 4 of 6 cases while in 2 of these patients the decrease of the involuntary movements was only moderate (duration of observations up to 14 months). Of special interest is a patient in whom the athetotic movements were associated with an opisthotonus particularly of the cervical spine which latter phenomenon could be abolished nearly completely by unilateral operation.

R.S., a 17-year-old white male, was admitted to Temple University Hospital on Nov. 25, 1962

| Table 2: Effects of campotomy in various conditions |
| ----------------- | ------------ | ---------------- |
| Disorder         | No. Cases   | Result          |
| Myoclonus        | 1           | Clonic movements reduced |
| Posthemiplegic   | 1           | Initially reduced, but recurred |
| tremor           |              |                  |
| Athetotic        | 6           | Definite reduction 4, slight reduction 2, recurrence 1 |
| movements        |              |                  |

Fig. 8. Electromyogram of extensors (E) and flexors (F) of left (l) and right (r) forearm in a parkinsonian patient with right-sided tremor. A before, and B after left-sided campotomy.

Fig. 9. Myotonogram showing resistance to passive extension (E) and flexion (F) in right elbow of a parkinsonian patient before and after left campotomy.
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with a history of birth palsy, severe athetoid movements and tremor. The abnormal movements appeared immediately following birth and were bilateral, but more manifest in the left arm and hand. At times the athetoid movements were so severe that he had to sit on his hand in an attempt to stop them.

The head was markedly retracted dorsalward and the trunk was hyperextended. There was bilateral ataxia. The combined effect of the athetosis and ataxia was so severe on the left side that it was impossible to perform the finger-to-nose test on this side. Spasticity was present on both sides but more pronounced on the left than the right. Writing was jerky and slow and speech was moderately dysarthric. He attained the 13th grade in school and was doing satisfactory school work without tutoring.

A right campotomy was performed on Nov. 29, 1963.

Following operation there was a marked reduction of the athetoid movements on the left side. The finger-to-nose test was performed with greater ease and accuracy. The spasticity was unchanged. The most remarkable change was the abolition of the abnormal movements of the head and the disappearance of the opisthotonus of the head. His trunk assumed a more nearly normal position so that his gait was improved. Writing and speech were unchanged. There developed deviation of the left eyeball downward and inward. When last seen 9 months after operation the ocular weakness had almost cleared and the reduction of the abnormal movements was maintained.

Regarding undesirable effects of campotomy in the present material (32 cases with unilateral and 1 with bilateral, two-stage operation), 1 patient with advanced generalized parkinsonian tremor died 2 months after operation. In 1 patient there appeared analgesia on the opposite side that persisted for 1 week.

Transient hemiplegia appeared in 2 cases, lasting 24 hours in 1 and 3 weeks in the other, a weakness of the opposite facial muscles occurred in 1 case (2 weeks in duration), ptosis in another case (5 weeks in duration), weakness of convergence in 1 patient and paresis of single muscles of the eye (internal rectus, inferior oblique, superior rectus) in 3 cases. These ocular symptoms improved at least partially in the course of several months. Further observations will have to ascertain whether residuals will remain. It already has been pointed out that in view of the appearance of eye-muscle paresis in these cases the technique was changed for lesions in front of the nucleus ruber. The stylet is directed anteromedially instead of medially and its length has been reduced from 3 to 2 mm. for these anterior lesions. Since these changes in technique have been adopted, eye-muscle paresis has become rare.

There were, at the most, slight and transient (2 weeks in duration) ataxic disturbances demonstrable, for instance in the finger-to-nose test in 1 case. Hemiballistic movements did not appear as a consequence of these lesions.

A transient depression in the level of con-
sciousness ranging from drowsiness to deep sleep appeared in 7 among the 33 cases (21.2 per cent). Other psychic disturbances, with or without preceding depression of the level of consciousness (Table 3), appeared in 10 patients (30.3 per cent). These psychic disturbances apparently correspond to the unspecific, so-called psycho-organic syndrome of other authors that has been found following pallidotomy and thalamotomy (Mundinger and Riechert in 31 per cent, and Müller and Yaşargil in over half of their patients operated upon). Partial interruption of the fibers of the reticular activating system passing through this area may play a part, particularly in the genesis of transient depression of the state of consciousness. The importance of the age of the patients in the appearance of the psychic disturbances in our material is evident if one considers that among 23 patients below 59 years only 2 had a short-lasting somnolence and only 4 had other transient psychic disturbances (Table 3), while in the group above 59 years (10 patients) transient disturbances of consciousness appeared in 5 and transitory psychic changes with or without preceding depression of consciousness in 6 patients. These disturbances lasted from 1 day to several months.

Discussion

The question arises which systems, when interrupted, may be responsible for the beneficial effect of campotomy upon tremor and rigidity. Since pallidotomy induces similar changes and since the effect of pallidal stimulation upon the tremor elicited by stimulation of the reticular formation still may be observed after elimination of the frontal lobe and degeneration of the fibers descending from this lobe and from the motor region, it seems probable that elimination of the pallidofugal fibers plays an important role also in the effect of campotomy. Corticofugal impulses passing through the prerubral field

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs.)</th>
<th>Depressed Consciousness</th>
<th>Confusion</th>
<th>Memory Defect</th>
<th>Apraxia</th>
<th>Negativism</th>
<th>Depression or Emotional Instability</th>
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<tbody>
<tr>
<td>Patients under 59 years old—23 cases</td>
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<td></td>
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<tr>
<td>17</td>
<td>52</td>
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<tr>
<td>26</td>
<td>46</td>
<td></td>
<td>Mild</td>
<td>1 mo.</td>
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<tr>
<td>28</td>
<td>52</td>
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<td>30</td>
<td>52</td>
<td>24 hrs.</td>
<td>Recent events, 6 wks.</td>
<td>3-4 days</td>
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<tr>
<td>32</td>
<td>52</td>
<td>24 hrs.</td>
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<td>33</td>
<td>54</td>
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<tr>
<td>Total</td>
<td></td>
<td>2</td>
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</tbody>
</table>

| Patients over 59 years old—10 cases |
| 6        | 66         | 24 hrs.                 |           |               |         |            |                                   |
| 7        | 65         |                         |           |               |         |            |                                   |
| 11       | 60         | 5 days                  |           |               |         |            |                                   |
| 16       | 59         | 24 hrs.                 |           |               |         |            |                                   |
| 23       | 67         | 10 days                 |           |               |         |            |                                   |
| 29       | 74         | Several days fluctuating|           |               |         |            |                                   |
| Total    |            | 5                       |           |               |         |            |                                   |

Grand Total 7

Total 10
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and pathways descending from the ventrolateral area of the thalamus also may play a role; it may be recalled that the influence of stimulation of the ventrolateral region of the thalamus upon the tremor induced by stimulation of the reticular formation was not prevented by degeneration of fibers descending from the frontal cortex, the sigmoid gyri and the pallidum.22

Compared with pallidal lesions, campotomy seems to have the advantage that a relatively small lesion may interrupt nearly all pallidofugal fibers; in order to obtain a comparable effect by a pallidal lesion, a rather extensive injury including the most caudal and medial parts of the pallidum would be necessary. If such a large lesion is produced, there is considerable risk of impairment of the internal capsule by encroachment of the injury or by interference with the arteries passing through the pallidum to the internal capsule. Ventrolateral thalamotomy also must extend to the close vicinity of the internal capsule in order to be effective, while the lesion produced by campotomy may be kept at some distance from the cerebral peduncle, so that as a rule at the most only an occasional, transient hemiparesis is observed.

The possible role of elimination of ascending pathways from the nucleus ruber and from the deep cerebellar nuclei also has to be considered. The elimination of cerebellofugal fibers probably does not play a significant part in the mechanism of the therapeutic effect upon the tremor. This is indicated by the observations of Delmas-Marsalet6 who found the parkinsonian tremor increased after ablation of the deep cerebellar nuclei. Tóth34 noted decrease of tremor in 2 of his cases and increase of this phenomenon in a third after this operation. The possibility, however, should not be denied that decrease of rigidity may be at least partly caused by the elimination of cerebellofugal fibers since Delmas-Marsalet6 and Tóth34 observed diminution of the parkinsonian rigidity following removal of the dentate nucleus.

In view of Rademaker's survey of extensive lesions of the ruber associated with hypertonicity of skeletal muscles, it should be emphasized that an increase of resistance to passive movements was not observed in any of our cases following the stereotaxic lesions; also if the coordinates of these lesions indicated that parts of the nucleus ruber were included in the lesions, existing cogwheel rigidity could be reduced or abolished. The differences between our and Rademaker's observations probably are ascribable mainly to the fact that in our material only parts of the nucleus ruber were injured (chiefly its anterior and lateral region containing mainly the parvicellular part), while in the material collected by Rademaker the nucleus ruber was destroyed more or less completely; the possibility should be borne in mind, however, that the hypertonus in his cases was at least partly caused by encroachment of the lesions upon other areas of the midbrain.

It seems of interest that the elimination of cerebello- and rubrothalamic fibers in Forel's field induces at the most very slight and transient ataxic disturbances. This is in agreement with the observation of Carrea and Mettler3 that the sectioning of these systems in front of the nucleus ruber did not induce ataxic disturbances in monkeys. The possibility that interruption of pallidothalamocortical fibers10 may play a part in the therapeutic effect should not be denied but has not been proven as yet. Such proof perhaps could be supplied by histological studies if it could be shown that the addition of a lesion of pallidothalamocortical fibers to a lesion of the descending fibers from the pallidum and ventrolateral nucleus could improve the therapeutic results.

The decrease of athetotic movements may be caused partially by a lesion of corticothalamic or corticofugal fibers in Forel's field, besides the lesion of pallidorubral and pallidotegmental fibers.

The interruption of fibers innervating conjugate movements of the eyes and coursing from the cerebral peduncle through Forel's field to caudal regions did not induce disturbances of volitional conjugate movements of the eyes apparently because only a
part of the impulses innervating such movements is conducted by these fibers. Vegetative disturbances also failed to appear following these lesions except for occasional transient extrasystoles immediately after the production of the lesion. It already has been mentioned that a lesion of ascending fibers of the reticular activating system may play a role in the production of transient disturbances of consciousness observed in some of the patients.

Summary

The method of campotomy, i.e. interruption of the fiber systems passing through and destruction of the cells located in Forel's field by stereotaxic approach, has been developed. It attempts to avoid injury to neighboring structures (thalamic nuclei, substantia nigra, corpus luysi, cerebral pedunca, oculomotor fibers). It has been applied to the treatment of parkinsonian tremor and rigor, of myoclonia and of athetotic movements. The beneficial effects regarding tremor and athetotic movements probably are the result mainly of the interruption of pallidofugal, corticorubral and corticotentential fibers. In the relief of rigidity lesions of cerebellofugal systems also may play a part.

References

26. Paper, J. W., and Stoffler, W. A. Connections of


**Discussion**

Dr. Russell Meyers: These three papers* represent a very welcome contribution to the experimentation and surgical therapy of the hyperkinetic and hypertonic disorders. I am sure Dr. Spiegel and Dr. Wycis, whom we may indulgently count as “oldies” in this realm of endeavor, warmly welcome relative newcomers, like Drs. Bertrand and Andy.

The place of these three papers in respect of their contributions can perhaps be seen best in a brief historical perspective in which we recognize that, during the past 24 years, since the first operations were done on the basal ganglia, there has been a distinct preference for these approaches over and against the cortical, spinal-cord and midbrain approaches that were antecedent to and somewhat overlapped them. Truly, we can count some genuine surgical therapeutic progress so long as we limit our cases to carefully selected patients; and perhaps we can count a small degree of illumination of the pathogenesis of disorders of abnormal movement and of disorders characterized by rigidity. Still, I would emphasize, as I have many times before, that we are decidedly in the developmental stages of this kind of work and that the long-term value of this kind of surgery as yet is far from established.

The intuitive phase of development of this work may be said to have covered the period from about 1939 to 1942; it was interrupted by World War II, and then the empirical, confirmatory stage came in 1947 and 1948. We passed through a “qualitative phase,” in which positive and negative evidence was gathered fairly rapidly from 1948 to 1955, and this phase told us something about where we might make lesions advantageously to get desirable surgical therapeutic results. If we wish to envision this “where” very briefly, we may think of a funnel with a hopper at one end, a narrow neck, and a hopper at the other end. At one end of this neural configuration, we find the globus pallidus; at the intermediate portion of its course, the ansa lenticularis; and at its other end, those portions of the pretectal region that have been spoken of this morning, namely, the substantia nigra and Forel’s fields. Lastly, there is a widening out of the mouth of the funnel, that being the ventrolateral nucleus of the thalamus and immediately neighboring structures.

We are unable to say whether interruption of the downgoing, the upcoming or the intermediate connecting elements of this complex are responsible, when interrupted, for the pathogenetic alterations that produce a favorable surgical result. However, empirically, it is clear that a larger lesion must be made to get a similar effect when we direct our surgical efforts at either one of the hoppers of the funnel; and that a very small lesion along the funnel’s neck may prove equally efficacious (and be less dangerous) than larger lesions at either end of this source-and-sink complex.

The papers we have been privileged to hear this morning signify that we have moved into a “quantitative phase” of the development of this work. The beginning of this phase can be said to have been about 1955. This is a phase in which biophysical engineering and monitoring techniques have been enormously to our observations.

We are now concerned, as these three papers reveal, with two general issues: first, deciding how extensive a lesion needs to be made (and be made safely) in order to achieve therapeutic results; and second, improving control, in order to reduce complications and make our results more predictable and enduring.

It is clear from the work that has been reported today that it lies within the realm of achievement within the next few years to construct three-dimensional physiological maps of the human brain, comparable to those sophisticated anatomical atlases with which we are now familiar.

Dr. Fry and I, working with ultrasound, fully concur in the observations made by Drs. Andy, Spiegel and Wycis, namely, that Forel’s field appears to be the most sensitive and vulnerable of the structures that make up the funnel. We have now performed over 55 such irradiations with ultrasound and feel quite satisfied that, to date, this is the most sensitive and at the same time the safest region to attack.

There yet remains the matter of illuminating for ourselves the pathogenesis of the abnormal disorders of movement with which we have been dealing; but a few things may now be said to have emerged from studies carried out during these past 25 years. One is that the operations, no matter what their technic and no matter

* The third paper presented was “Electrical Exploration of the Internal Capsule and Neighboring Structures during Stereotactic Procedures,” by Gilles Bertrand, John Blundell and Rosario Musella.
what noxious agent they employ to induce lesions, are nonspecific; that is to say, they are not directed at the site(s) of pathologic change producing the abnormal movement and tonic disorders (whatever those changes may be!): and, secondly, they are nonspecific for a particular pattern of abnormal movement, for they are effective against alternating tremors, ataxic tremors, ballistic, myoclonus, etc.; third, it appears as if the neural complex, that pallidolugal complex of which we have been speaking, constitutes an important member of the several suprasegmental agents that normally monitor the lower-motor neurons. It appears that, if this agent is interrupted, we abrogate at least one of those agents, the integrity of which is necessary for the perpetuation of tremor and rigidity. Unfortunately, while effective for the relief of tremor and rigidity, the operation leaves unaltered the group of signs and symptoms subsumed by the loose term, akinisia. Thus far, we have discovered no operative procedure effective against akinesia. These happen to be matters more than two-thirds of our patients exhibit postoperatively. With our approach from above, turning a micrometer screw, one can have definite differentiation of the cell groups, even on a loudspeaker, as the electrode goes through V.L. and then through V.P.L. and on through the zona incerta of the thalamus, which prolongs the “zone grigliée.”

[Slide] As shown on this slide, it is no longer necessary to summate activity as with the method published by Vernon Mark. This was evolved gradually by Fessard, Guiot and Hardy using the posterior approach of Guiot. With our approach from above, turning a micrometer screw, one can have definite differentiation of the cell groups, even on a loudspeaker, as the electrode goes through V.L. and then through V.P.L. and on through the zona incerta of the thalamus, which prolongs the “zone grigliée.”

[Slide] Shown on this slide is the point from which tremor can be best interrupted in most cases, that is at 13 mm. from the midline, at 16 mm. posterior to and 8 to 10 mm. below the center of the foramen of Monro, the discharge becomes synchronous with tremor; that is, one can see on the slide a cell discharging at 5 per sec. which stops discharging when tremor stops. More interesting to the neurosurgeon is the fact that tremor stops immediately as the electrode progresses through this point so that we now have definite proof as to its role in production and control of tremor. However, Guiot found a similar zone somewhat higher and lateral to the thalamus so that one cannot conclude that the effect obtained is caused by pallidofugal fibers or any other group of cells or fibers.

The results of stimulation obtained by Dr. Gilles Bertrand confirm ours and those of Guiot. As a note, the lateral limits of the motor points of stimulation are again at 18 mm. from the midline in most individuals. Stimulating as we do below the site of the proposed lesion and then at and above this site, is preferable for us since a lesion is to be placed above the corticospinal tract as it enters the cerebral peduncle, at and below V.P.L. As we have said before, the constancy of these points of stimulation in the cerebral peduncle is even greater and a difference of 2.0 mm. may change stimulating response from arm to leg.

Sensation in the leg was obtained almost as easily as in the arm and I presume that if Dr. Gilles Bertrand did not obtain it, it was merely because his stimulation did not extend posteriorly as much as ours. Incidentally, a lesion situated farther posteriorly than this will not be more successful for tremor and carries a greater risk of leaving the patient with persistent dysthesiae or even, as in one instance, a form of thalamic pain. This, incidentally, does not come from the thalamus but from the subthalamic portion of the lemniscus, as evidenced by the numerous thalamotomies performed without producing it.

In conclusion, the optimal zone seems to be situated partly in the subthalamus immediately below V.P.L. Posteriorly one must avoid sensory fibers; posteroinferiorly and mesially the fibers of the 3rd nerve; mesially the mammillothalamic tract, which some believe has a function in the processes of memory; anteriorly and inferiorly, the corpus luysi and laterally as well as inferi-
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orly, the corticospinal tract and, also, the speech association fibers. That is why it is so important to use not one but all physiological means at one’s disposal for accurate localization and protection, which can be almost 100 per cent, and there is no doubt that spontaneous cellular activity, when used properly, seems to be the most accurate tool at our disposal at present.

Dr. John Van Buren: The papers by Dr. Andy, Dr. Bertrand, Drs. Spiegel and Wyceis and their collaborators again underline the unparalleled opportunities which we now possess in stereotactic surgery for study of basic human neurophysiological mechanisms. It has often come to mind that we are entering a frontier with depth studies similar to those that the exposed cortical surfaces of man presented to Dr. Penfield and others not so many years ago.

I have been more than pleased to note that all the essaysists have given their localizations not only in terms of probable anatomical structures entered but in terms of coordinates related to the commissures and the intercommisural line. This makes it possible for the rest of us to apply their findings in our own work and is mandatory if information of basic scientific values is to be accumulated.

[Slide] This slide shows the superimposed outlines of 16 brains ranging from 1050 to 1750 gm. in weight, the section being taken 5 mm. from the midline. On the left, all brains were aligned by use of the anterior commissure, while on the right all were aligned by the posterior commissure.

With regard to the tegmental placement anterolateral to the red nucleus, I would underline the importance of using the posterior commissure as Dr. Spiegel and Dr. Wyceis do for this localization. As you see, the set that is oriented with regard to the posterior commissure shows a considerably smaller outline of the red nucleus than the one oriented from the anterior commissure, thus the variation in tissue is considerably less using this landmark.

Finally, I might comment on a point of confusion that has arisen frequently regarding the interchange of data from depth stimulation. It is not enough to give, for example, the voltage used in the stimulation. For someone else to be able to reproduce the conditions of stimulation one must know to begin with 2 of the 3 factors of Ohm’s law, namely, amperage, voltage or effective resistance, as well as the wave form and the type of current. In addition, when using intermittent DC pulses such as are supplied by the commonly available stimulators, the resistance of the dielectric layer formed about a polarizable electrode varies in an inverse but nonlinear way with the current passed. Thus it is not enough to give the resistance of the electrode in situ determined with a low-current ohmeter, since this value will be far in excess of the resistance of the electrode when it is passing current in the range of stimulation.

Dr. O. J. Andy: First, to answer the question by Dr. Meyers with respect to speech: in the 1 patient in whom we did place a bilateral lesion in the subthalamic area, there definitely was a disturbance of speech. This was quite pronounced at first. It is 2 years since her second operation and she is starting to speak with fairly good volume and understanding.

The other question that Dr. Meyers asked concerns the duration of the results. The patients on whom I presented results have been operated upon over the past 7 years, so they definitely do not fulfill the common requirement of a minimum 5-year follow-up. I think it requires more than 5 years of observation.

The shortest period of time was represented by 3 of these patients, which was 4 months.

The next comment concerns Dr. Bertrand’s point. I don’t know whether or not he misunderstood my comment. He stated that I intimated 13 mm. from the midline was the optimum site. Our optimum site is much more medial, and I would estimate at least 8 to 9 mm., and 10 mm. at the most. I would go along with Drs. Spiegel and Wyceis on this.

Dr. E. A. Spiegel: I am very happy to note the high degree of agreement in the discussion. I completely agree with Dr. Meyers that we need long-term observations. Our own observations following pallidoanotomy go back to 1948, covering a period of nearly 15 years.

The problem whether the therapeutic effects in tremor are the result of interruption of ascending or descending fibers cannot be answered definitely at the present time. I believe there is some indication from experimental results. We tried to produce experimental tremor by stimulating the tegmentum of the midbrain and found we could increase this tremor by stimulating the pallidum or the ventrolateral area of the thalamus; the pallidal or the thalamic effects could still be observed after complete degeneration of the fibers descending from the thalamus to the cortex activating the motor area. This doesn’t exclude, of course, the possibility that ascending fibers to the motor and premotor areas also are involved in the mechanism of tremor.

I agree with Dr. Meyers that what he calls the “neck area,” is a very favorable location for placing stereotaxic lesions in extrapyramidal disorders. Here in Forel’s field we can obtain by small lesions injury to both the ascending and descending fibers concerned. I am a little skeptical about the possibility of improving the akinesia because by these operations we eliminate impulses and by taking something away we can’t hope very much to improve the voluntary activity of the patient.

As Dr. Bertrand has pointed out, one should always avoid the area of the corpus luyisi as well as the mammillothalamic tract; we place our lesions, therefore, caudally to the latter system and medially from the medial end of the corpus luyisi.

The finding of rhythmic discharges in suprasegmental areas corresponding to the tremor is, of course, very interesting. As you know, there have been relevant experiments going on in the Montreal laboratories, and Jasper and his associates (Cordeau, Gylbels) found in monkeys with experimentally produced postural tremor rhythmic discharges in microelectrode studies from the sensorimotor area of the cortex, as well as from the basal ganglia. Our group is at present also engaged in
microelectrode studies recording unit discharges in the pallidum simultaneously with electromyograms from the shaking muscles. It is very difficult to draw conclusions from these microelectrode records because we do not know how far they represent tremorogenic impulses or how far they reflect the tremor. In my laboratory Dr. Szekely recorded unit discharges, e.g. from the pallidum of cats, and found that sensory impulses induced by passive movements of the paws are reflected in the unit discharges from various areas. I believe, therefore, that the question whether we are dealing in these rhythmic unit discharges with tremorogenic impulses or simply a reflection of centripetal impulses coming from the shaking limbs is not solved as yet.

There was just now a paper read at the meeting of the Federated Societies in Atlantic City by Lamarre and Cordeau who tried to solve this problem by correlation analysis. They still found during periods without tremor unit discharges from various cortical and subcortical areas. I believe that these interesting records present also not quite sufficient proof, although in these studies there were periods without visible tremor. All who have dealt with electromyograms in postural tremor know very well, and I am sure Dr. Meyers will agree, that there may be rhythmic discharges from the muscles in parkinsonian patients, although we don't see the tremor. Thus finding no tremor on simple inspection is not quite sufficient and the question whether there is a central pacemaker for the parkinsonian tremor and where it is located does not seem solved as yet.

I agree with Dr. Van Buren that the localization of stereotaxic lesions is the more exact the closer it is to the reference point, as has been emphasized in our monograph. We use the intercommissural line and particularly the posterior commissure for reference in localizing the field H, so that the danger of error caused by individual variation is minimized as far as is possible. The stimulations performed prior to the production of lesions are a further safeguard to avoid false locations because of individual variability.

DR. HENRY T. WYCS: Very early in our work we used the Bovie current, but we couldn't control the spark gap and obtained heating along the path of the electrode. However, Dr. Andy had better success with this type of current.

As Dr. Spiegel stated, we avoided making a lesion in the region of the corpus subthalamieum because we wished to avoid the production of hemiballistic movements. Such movements have been reported when lesions were placed inadvertently in the region of the corpus subthalamieum. Carpenter has shown that if one destroys 20 per cent of this structure, movements will appear. On the other hand, if the lesions are extremely large, the movements do not appear.

I believe, perhaps, that the lesions made by Dr. Andy interfered with some of the pallidosubthalamicus circuits.

Regarding the question of Dr. Russell Meyers about bilateral lesions in the campus Foreli, we also have made bilateral lesions in this structure and in 1 case that comes to mind, bilateral lesions did not result in any serious side effects. This may be because we waited a sufficiently long time between operations. It usually is our practice to wait at least 6 months in these cases before doing the other side. In those cases in which we have any complications on one side, we are hesitant to do a similar type of procedure on the other side. Dr. Meyers spoke about a "quantitative" phase in the development of this work. I believe this phase started in 1947 with the use of guided electrodes in the human brain.