Quantitative Criteria for the Neurosurgical Treatment of Parkinsonism*

Joel Brumlow, M.D., Nicholas Wetzol, M.D., George Potter, M.D.,† and Mathew Petrovick, B.S.E.E.

Departments of Surgery, and Neurology and Psychiatry, Northwestern University Medical School, Chicago, Illinois

Although the syndrome of parkinsonism first was described almost a hundred and forty years ago, it has been only within the last decade or so that neurosurgical approaches to the treatment of this disease have been feasible. In the past several years, we have been interested in the development of measures of the disabilities that this disease produces, both in regard to the fundamental problems of neurophysiology and particularly with reference to the development of objective criteria by which the natural course of the disease and the effects of drugs, surgery, and physiotherapy may be studied. The present report is a preliminary study of some of the methods that have been developed for the pre- and postoperative study of parkinsonian patients who have undergone thalamotomy for their symptoms and describes a technique whereby the surgical procedure itself can be monitored.

Neurosurgical approaches to the treatment of parkinsonism in the past have included lesions placed in all levels of the central and peripheral nervous systems. In the last few years, most attention has been placed on the development of methods of producing lesions either in the globus pallidus or ventrolateral nucleus of the thalamus, with acceptable rates of mortality and morbidity. If properly selected, “good” results have been reported in 80 per cent of subjects under 40 years of age with early symptoms, involvement restricted primarily to one side, and with rigidity and tremor (as opposed to bradykinesia) as main symptoms. As the symptoms become bilateral and the patient more elderly, particularly with axial involvement and bradykinesia added to the picture, the results are said to fall to 70 per cent and then to 40 per cent of all patients. It has been estimated that there are at least 266,000 patients with parkinsonism in the United States, of which only a small portion fit the criteria of Cooper and others for good results.

There are many unsolved problems in the neurosurgical approach to parkinsonism.

1) The problem of “good results”: definition of terms. It is observed commonly that the disability in parkinsonism varies from person to person and from time to time in the same person. Some patients are able to work with relatively severe symptoms and signs of disease, while others are incapacitated by the mildest objective dysfunction. Moreover, relief of rigidity and tremor has followed an operation which also produced a major psychosis; in another instance, death has resulted from respiratory insufficiency. It is, therefore, not sufficient to separate results into “good” or “bad,” but each symptom must be included and weighed in its own right.

2) The problem of symptoms: the treatment of a syndrome, not a disease state. The symptoms of parkinsonism may be caused by many different etiologic agents, but the surgical approach is based on the premise of a common disturbance in neurophysiology and is directed at a set of symptoms, and not a disease entity. In this sense, it might not be unexpected that relief might be symptomatic and, therefore, uncertain both in degree and in nature.

3) The problem of follow-up: the variation in the postoperative state. The postoperative results are not yet uniform and cannot be predicted with complete confidence at the time of operation. Immediately after thala-
motomy, the symptoms may disappear, only to return in full force after a variable length of time. The reverse also has occurred, in which an operation was apparently a failure only to be followed by the gradual diminution of symptoms and signs over a period of time.

4) The problem of the uniformity of procedure: size, site, and nature. To add to the problem of other uncontrolled variables, there is wide variation among neurologic surgeons as to the ideal size, site, and nature of the lesion to be produced. Lesions have been produced mechanically, chemically, with radioisotopes, and by a variety of electrical or electronic means, including electrocoagulation and radiofrequency currents (primarily producing heat), and physically with ultrasound. The recommended site of the lesion has varied, some authorities suggesting that the lesion be “as large as possible.” The ideal site of the lesion is still in dispute, but the current targets of choice are the ventrolateral nucleus of the thalamus, or perhaps, the globus pallidus. No matter what locus is selected, the problem of placement of the lesion still remains. Techniques may range from rather freehand technique, more or less controlled by roentgen rays, to elegant techniques employing stereotactic apparatus and basing the placement of the lesion by relationship to other cranial and intracranial structures. However, because of the wide variation of anatomic structure of the human brain from patient to patient, we have attempted to achieve some type of neurophysiologic correlation so far as the placement of the lesion has been concerned.

5) The problem of contaminated results: drugs and physiotherapy. It would seem obvious that surgical results must be evaluated in their own right; but the effects of surgery usually are measured during a postoperative period of intense physical therapy and/or management with drugs. Neglecting for a moment the profound influence of the operation per se on the symptoms (the “placebo” effect of surgery, as described by Beecher), the results of surgery must at least be equal to, or better than, other forms of treatment in order to justify the procedure. Ideally, the results should not be confused with those of simultaneous treatment with drugs and physical therapy.

6) The problem of disability and candidacy for surgery. We have already alluded to this problem in the average parkinsonian patient, a person with rigidity, tremor, and other disabilities, but who is crippled primarily by a symptom not yielding readily to surgery, that is to say, slowness of movement. The age group of the parkinsonian patient is crowded with other hazards: organic mental changes, affective psychotic disturbances, and the like. In the majority of parkinsonian patients, surgery may or may not be of sufficient benefit to justify the procedure.

To answer these questions, we have proposed that each patient undergoing surgery for parkinsonism be subjected to a careful clinical study before and after operation until at least 6 months have elapsed following the procedure. A detailed neurologic examination should be done, including a clinical rating of each symptom and sign, together with careful mental evaluation. If there is indication for drugs and physical therapy after surgery, this should be noted, so that such subjects are not equated to those not receiving the benefit of such treatment. Measurements of the activities of daily living must also be made. If these data can then be correlated later with the surgical procedure and its results, then a meaningful pattern may eventually evolve to outline the criteria for surgery, as well as for the procedure itself. Our efforts, as have those of other investigators,21 have evolved in the direction of serial electronic measurements of the various symptoms. Currently, slowness of movement, rigidity, tremor, voice, articulation, respiration, and the psychologic state of the patient are all recorded in permanent and quantitative form, as well as in the usual clinical fashion. In addition to these pre- and postoperative measurements, we have also attempted to monitor the surgical procedure itself, using the most easily recorded sign, the tremor of the limb. Our present system utilizes a variable reluctance acceler-
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ometer which is small, easily applied, and which does not interfere with the surgical procedure itself. During the operation the continual variations of tremor are recorded permanently, and the responses of the limb to stimulation, the production of lesions, etc., may be followed. It is to be hoped that the correlation of these surgical records, the preoperative data, clinical follow-up evaluation, and such autopsy material as may become available, may eventually provide answers to some of the problems that are outlined above. Such a long-term study may also provide a moment-to-moment monitor for the surgeon so that he may be able to gauge the site and adequacy of the lesion with greater confidence.

Methodology

A. Selection of Patients. No definite effort has been made to select subjects according to rigid criteria. The patients that have been operated upon were usually those who had not yet experienced sufficient relief, in their own opinion, after trial on therapy with drugs for at least 6 months. Patients with far advanced disease recently have been excluded from the surgical-therapy group. Several patients have fulfilled these suggested criteria for surgery; a young patient with primarily unilateral symptoms, coupled with an absence of other neurologic involvement, especially without evidence of mental change.

B. Instrumentation. The methodology for the pre- and postoperative clinical and quantitative electromechanical methods has been described previously.1,5,7,8,15,18-20 The present report will describe the measurement of tremor during operation and its use as a quantitative prognostic criterion.

At operation (Fig. 1) tremor is sensed by several AVR-250* accelerometers which are taped to the index fingers. The thumb of the hand contralateral to the side of the lesion also is recorded. The signals from these accelerometers are fed to a modified Sanborn 150 polygraph for detection and recording.

* Gulton Industries, Metuchen, N. J.

The upper limbs of the subject are extended and unsupported distal to the elbow. Thus, motion is unimpeded, and the surgical procedure is not hampered. By means of calibration curves, the tracings are analyzed for amplitude, frequency, and particularly waveform of the tremor, including the presence of normal tremor, as opposed to parkinsonian pattern.6 The fourth channel of the polygraph is occupied by the output of a Grass S4C stimulator which is used to deliver stimuli to various subcortical structures. The voltage and frequency of the imposed stimulation can be read directly from the record, as well as relationships to changes in tremor that may be produced.

Current efforts are directed at achieving fully annotated records for further study. In addition to the surgeon and his assistant, a separate observer records the surgical procedure from a clinical standpoint, noting the effects of stimulation, the position of the stimulating electrode, the type of stimulation, and the like. A third member of the team is in charge of the electronic equipment and also records such details as gain settings and reports changes of tremor during the procedure. Eventually, the principles of simultaneous magnetic tape recording may
be applied to preserve data from all sources and to reduce some of the inevitable difficulty that results from such a procedure.

C. Surgical Procedure. The stereotactic procedure has evolved over a considerable period of time, and several human stereotactic devices have been used. However, the preliminary placement of electrodes always has been made only after pneumoencephalography and/or Pantopaque ventriculography, taking into account various distortions that occur because of the divergence of the roentgen-ray beams, etc. Most recently, the stereotactic apparatus of Leksell has been used. Various types of electrodes have been employed, both for stimulation and recording; these have been of either silver or stainless steel, with several millimeters of electrode available for stimulation or recording. Monopolar technique generally has been used. At various times, a bank of five electrodes has been used, with the electrodes being arranged so as to correspond to the four corners of a square, the center of which presumably is located in the target area. It has been assumed that the lateral electrode would thus be 5 mm. nearer the internal capsule than the central electrode, the posterior and anterior electrodes each 5 mm. away in the sagittal plane, and the medial electrode 5 mm. nearer the midline. Theoretically, the clinical effects of electrical stimulation of the electrodes in a systematic fashion with varying frequency and voltage of stimulation provide an indication as to the position of each. If the stimulation evokes a contralateral motor response synchronous with the imposed stimulus, it might be presumed that this electrode is in or near the internal capsule. With low-voltage stimulation producing such a response from the lateral electrode, the latter is presumed to be placed correctly, and, therefore, a lesion just medial to this point should involve the desired thalamic nucleus. If, on the other hand, a low-voltage stimulus to the medial electrode were to produce such a response, with none from the lateral electrode, it might then be presumed that the electrode group as a whole had been placed too far laterally. Unfortunately, there seems to be very little exact knowledge as to how far away in the internal capsule one must be in the human to obtain an evoked motor response on the opposite side with a given voltage.

At operation, stimulation of each electrode is carried out using 1 msec. pulses at 3 to 6 per sec., with the voltage ranging from 2 to 20 V. The usual frequency was 3 per sec. Lesions have been made either with a leukotome or, most recently, radiofrequency current to produce a lesion approximately 1 cc. in spherical diameter by heating the area of the brain to 62°C. for 2 min. In several cases, in which placement of the electrodes has been uncertain, a single electrode has been left implanted for several days with further stimulation and a subsequent lesion.

D. Analysis of the Record. The polygraph tracing is correlated with the observer's clinical comments and other material such as tape recordings, listing each event at operation under the following headings: 1) nature, frequency and amplitude of the tremor before, during, and after each stimulation; 2) the position, voltage, and frequency of each stimulus; and 3) the contralateral or ipsilateral responses in terms of evoked driving response or change in tremor. It is the latter that has most aroused our attention.

Results of the Study

A. General Statistical Data. Ten patients were included in the present study: 3 females and 7 males. The mean age of the group was 48.8 years (13.2 years younger than the mean age of a second series of patients who have been studied to evaluate the effect of medication with drugs). Of the 10 patients in this series, 4 were subjected to right, and 6 to left thalamotomy. The eventual result of surgery (see below) did not correlate with the side operated upon. The mean duration of illness was 8.7 years (2.2 years longer than the mean age of a second group of patients). Two patients had a past history of encephalitis and 1 reported a history of a similar illness in the family. No definite etiologic factor was noted in the other patients of the series.

B. Clinical Evaluation. Each category of
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symptoms was rated by the same examiner and coded according to a scale ranging from 0 to +3, the latter indicating severe involvement, the former no involvement. Three patients fell into the category of so-called "unilateral tremor" (P.O., C.H., L.I.). One patient (K.A.) had tremor approximately equal on the two sides, while the remainder of the group showed tremor bilaterally, worse on one side than the other. Two patients showed no improvement following operation and both were rated as "poor results." The remaining patients all showed some improvement. Included in this subgroup were 2 so-called "questionable" results, and 6 "obviously good" results. It is of interest to note that of the poor-result patients, 1 presumably was a good candidate for operation (47 years old, unilateral tremor, no other neurologic involvement, and no axial involvement). The second patient, however, fell into the presumably poor category (55 years old, with bilateral tremor, other neurologic signs, and axial involvement). Though 8 of the 10 patients showed no change in the tremor on the side ipsilateral to the lesion, 2 patients did show such a change. One patient (A.N.) showed improvement on the unoperated side, with a change from +2 to 0. The second patient (H.A.) showed improvement on the side contralateral to the lesion but worsening on the ipsilateral side (+1 to +3).

Although not tested quantitatively by electromechanical means, rigidity also showed change from the pre- to postoperative status. In most cases, improvement was noted, ranging from 1 to 2 subjective grades. This was true not only on the contralateral (or operated) side, but also on the ipsilateral (or unoperated) side, except in one instance (A.N.), when on the side contralateral to the side of the lesion, an increase of 1 subjective grade was noted (0 to +1). No change in the clinical evaluation of masked facies was noted. Motor weakness was noted in 4 patients after surgery, with subsequent improvement in 3, and no change in 1. In 2 of the patients who experienced hemiparesis immediately following surgery (A.L. and H.A.) no deficit was noted at the time of postoperative evaluation. No significant change was noted in voice, articulation, or slowness of movement. The same was true of gait, posture, and disturbances of the autonomic nervous system. In the preoperative neurologic examination, a hemiparesis was noted in 1 patient (B.O.), and weakness of the left side of the face in the other (A.N.). These were not elicited postoperatively. On the other hand, several patients exhibited neurologic signs other than those of parkinsonism in the postoperative evaluation. Five patients showed significant facial weakness on the operated side. Two of these patients (W.E. and H.A.) were rated as having obtained good results, whereas the 3 remaining patients were included in the questionable- or poor-result subgroup.

C. Quantitative Tremor Measurements, Pre- and Postoperatively by the Accelerometer Method. The range of variation of these parameters in the parkinsonian population was obtained from a study in which patients were measured while on placebo medication.8 The expected range of variation in amplitude of tremor is 9.3 mm. (or from −87 to +200 per cent). The expected range of frequency is 6.0 c./sec. and the per-cent time ballistocardiogram (BCG) 52 per cent. Four patients exceeded the expected range of variation in mm. of amplitude of tremor (Y.O., C.H., A.N., and H.A.).* One patient (L.I) was not available for objective operative follow-up. Five patients (A.L. in addition to the above 4) exceeded the expected range of tremor-amplitude variation when expressed as per cent of the initial value. Three patients exceeded the expected range of per-cent BCG variation (A.L., C.H., and A.N.).†

D. Over-all Evaluation of Results. Two patients reported either no improvement or worsening of their symptoms (P.O. and K.A.) following operation. One patient believed the result to be questionable, while the remainder were pleased with the results in that they were able to resume previously impossible

* None of the patients tested on medication exceeded either the expected amplitude or frequency range of variation.
† As compared to 4 patients on drug medication.
activities of daily living and/or occupations. The examiner concurred in every case, except 1 (B.O.) in whom the result was rated as questionable, even though the patient felt definite subjective improvement and was quite enthusiastic about it. Only 2 patients were not obliged to take medication following operation. The remainder of the patients, improved or not improved, all received some form of medication. One patient (W.E.) stated that he was forced to take medication or the tremor would return. These medications were mostly of the solanaceous group.

E. Surgical Records. In 5 patients, the lesions were made by mechanical means, and in 5 by radiofrequency current. In all cases, an attempt was made to place these lesions in the ventrolateral nucleus of the thalamus, according to the coordinates based on the anterior-posterior commissural line. The records of tremor were analyzed for two additional parameters: (1) a contralateral “motor response” (Fig. 3), presumably elicited with lowest voltage from regions in or near the internal capsule and (2) change of tremor, in which case the tremor was either reduced or increased in amplitude (compare Figs. 2 and 4), or else changed from a parkinsonian tremor to BCG, or vice versa (Fig. 5). Both motor responses and changes of tremor were elicited with greatest frequency with the lowest voltages from posterolateral electrodes. Voltages ranging from 2 to 5 V. elicited both motor responses and change in tremor in these areas. It was observed commonly that the clinical observer and the record were in disagreement as to the motor response. Since only 2 accelerometers were available for recording, motor responses from the platysma, shoulders, etc., often were not recorded from the hand if the latter was not involved simultaneously in the response. When the hand alone was involved, or if it moved simultaneously with other portions of

![Fig. 2. Surgery tremor record: A stimulus (bottom channel) may have no effect on tremor (upper channel) when (a) tremor is of parkinsonian type (upper graph), or when (b) tremor is a ballistocardiogram (lower graph). Bottom channel on each graph is the stimulus record, the on-off time and the frequency.](image-url)
the body, the accelerometer agreed with the observer's comments in regard to the determination of the motor response. Surprisingly, it was also common for two different clinical observers to differ with each other in the determination of the motor response, as regards voltage required, etc. Observers' comments, together with the results of the written record, were tabulated. The clinical observer also was found to be unreliable in the determination of change in tremor. It was difficult for the clinical observer to differentiate certain atypical motor responses from changes in tremor. At other times, spontaneous changes in the tremor occurred, often a fraction of a second before the stimulus was begun. This could be determined easily from the record, but could not be seen with the naked eye. Moreover, changes in tremor, when the latter was initially of low amplitude (below 1 mm.), could not be observed with the eye alone, and were, therefore, not recorded by the clinical observer. The sensitive accelerometers, however, permitted the analysis of these low-level changes in tremor.

The per cent of total stimuli delivered to each electrode causing changes in tremor and also the electrode from which tremor could be changed with the lowest voltage were noted. In 2 patients (K.A. and A.L.), no stimulus was effective in producing changes in tremor. In 3 other patients (P.O., W.E. and B.O.) only 1 stimulus out of more than 25 was effective in changing the tremor. On the other hand, in another case, as many as 30 per cent of all stimuli delivered was effective in changing the tremor. In 4 cases, change in tremor was noted following the initial im-

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**Fig. 3.** Surgery tremor record: A stimulus may produce a motor response ("driving") in the contralateral extremities. Note the rapid, brief clonic movement recorded by the accelerometer synchronous with each stimulus.
plantation of the electrodes. In 2 cases (H.A. and W.E.), this response was transient, with return of the tremor once the electrodes had been inserted. In the other 2 patients (C.H. and L.I.) the change in tremor was sustained; in 1 case, the conversion of the tremor to BCG and in the other, a reduction of the amplitude of tremor by 50 per cent. The immediate postoperative evaluation of the results of surgery did not correspond to the final evaluation, either clinically or by the accelerometer method. In 1 case (P.O.), an immediate postoperative result was excellent but was followed later by return of the tremor. A second patient (K. A.) showed no visible effect immediately after operation and has not shown any further change. The remainder of patients showed a progressive reduction in amplitude of tremor during the follow-up period. From Tables 1 and 2 it can be seen that those patients who were rated as either poor or questionable results showed little change in tremor, with good motor responses. In these cases, the lesion included the areas defined by the evoked responses obtained. Two further patients (Y.O. and L.I.) were rated as good results both clinically and by the accelerometer method. These 2 subjects had poor motor responses to stimulation at operation; the lesion did not include those areas from which these responses could be elicited. In the final 4 patients, good changes in tremor and motor responses were obtained. The lesions that were made included those areas from which these responses could be elicited. These findings are illustrated graphically in Fig. 6, in which the results of stimulation are superimposed on the site and size of the lesion and the presumed anatomical situation of the electrodes.

**Discussion**

As defined by the present study, four possible events may result from surgical stimulation with reference to tremor: 1) no effect may be obtained from stimulation of the subcortical structures; 2) parkinsonian

![Fig. 4. Surgery tremor recording: A stimulus may produce a marked attenuation of the amplitude of parkinsonian tremor, with or without accompanying contralateral evoked response (upper and lower records, respectively). Note delay between onset of change of tremor and onset of stimulus, and persistence of the change of tremor following cessation of stimulus, with subsequent escape and return of tremor to previous level.]
tremor may change to BCG or vice versa; 3) there may be an increase or decrease in the amplitude of tremor; and 4) there may be an increase or decrease in the frequency of the tremor. The last named event was observed only infrequently. It was difficult for the naked eye to observe these changes when the tremor was of low amplitude and it was especially difficult for the clinical observer to correlate precisely changes in tremor with stimulation. The advantages of the accelerometer method of recording tremor during operation are obvious: the clinical observer cannot differentiate changes in tremor from motor responses; tremor can change spontaneously though appear to the clinical observer to be the result of stimulation; the nature of low-amplitude tremor (BCG or parkinsonian type) cannot be identified visually; the clinical observer cannot observe rapid changes in tremor and correlate them instantaneously with stimulation, and different clinical observers do not always agree with each other during operation as to the results of stimulation. On the other hand, the written accelerometer record is not biased and rapid changes in tremor can be identified and

![Image](image-url)

**Fig. 5.** Surgery tremor record: A stimulus may change tremor from the parkinsonian type to BCG (lowest graph) or vice versa (top two graphs) with or without a contralateral evoked response. Top two records: with evoked response—BCG to parkinsonian tremor. Bottom record: without evoked response—parkinsonian tremor to BCG.

<table>
<thead>
<tr>
<th>Clinical Change in Tremor*</th>
<th>Clinical Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 to 3</td>
<td>2 Poor</td>
</tr>
<tr>
<td>3 to 1</td>
<td>1 Good, 1 Questionable</td>
</tr>
<tr>
<td>3 to 0</td>
<td>3 Good</td>
</tr>
<tr>
<td>2 to 1</td>
<td>1 Questionable</td>
</tr>
<tr>
<td>2 to 0</td>
<td>1 Good</td>
</tr>
<tr>
<td>1 to 0</td>
<td>1 Good</td>
</tr>
<tr>
<td>* 3 = severe</td>
<td>Total 6 Good</td>
</tr>
<tr>
<td>2 = moderate</td>
<td>2 Questionable</td>
</tr>
<tr>
<td>1 = mild</td>
<td>2 Poor</td>
</tr>
<tr>
<td>0 = normal</td>
<td>10</td>
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*Subjective clinical improvement compared to clinical evaluation of tremor*
correlated with the stimulation, even when the tremor is of low amplitude. Moreover, a permanent record is obtained for future study. One obvious disadvantage of using the accelerometer is that motor responses can occur in parts of the body other than those being studied by the accelerometer and thus not be recorded. The answer to this problem is the use of more than one accelerometer, and ideally many accelerometers could be used, placed at significant points over the body. The present study confirms the opinion of others that progressive changes ensue following surgical treatment. The immediate postoperative opinion as to the state of the patient is not always that which is obtained several months later; thus, adequate follow-up is essential.

On medication with drugs in another study,\(^8\) the amplitude of tremor did not change significantly more than it did on placebo; however, in certain surgical patients, the amplitude of the tremor was reduced significantly. The same was true, to a lesser extent, of the frequency of the tremor and also the per-cent time BCG. The former was not obtained with drugs, whereas the per-cent time BCG was altered significantly by trihexyphenidyl.\(^8\) Thus, it would appear that medication is most effective in changing the incidence of tremor over a given period of time such that, as the patient "improves," parkinsonian-type tremor is present a lesser period of time. Surgery, however, would appear to be effective in changing not only the per-cent time BCG but also the actual amplitude and frequency of the tremor. This implies that surgery attacks the fundamental neural circuits involved in the genesis of the parkinsonian tremor, whereas the same cannot be said of medications, which seem to have a less specific effect. These observations imply that, though it is desirable from the standpoint of follow-up care to measure the postoperative patient in the drug-free state, it may be quite rational to employ drugs following surgical procedures, since the two seem to have different mechanisms of

**Table 2**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Clinical Result</th>
<th>Present in Record Low Voltage</th>
<th>Lesion Includes Low Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Evoked Response</td>
<td>Changed Tremor</td>
</tr>
<tr>
<td>P.O.</td>
<td>Poor</td>
<td>+</td>
<td>+?</td>
</tr>
<tr>
<td>K.A.</td>
<td>Poor</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>A.L.</td>
<td>Questionable</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>B.O.</td>
<td>Questionable</td>
<td>+</td>
<td>+?</td>
</tr>
<tr>
<td>Y.O.</td>
<td>Good</td>
<td>+?</td>
<td>+</td>
</tr>
<tr>
<td>W.E.</td>
<td>Good</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>C.H.</td>
<td>Good</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>L.I.</td>
<td>Good</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>A.N.</td>
<td>Good</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>H.A.</td>
<td>Good</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No. Patients</th>
<th>Stimulus Results</th>
<th>Clinical Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Poor evoked responses</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>Good change of tremor</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Either &quot;?&quot; or &quot;no&quot; changes of tremor</td>
<td>Poor or questionable</td>
</tr>
<tr>
<td></td>
<td>Good evoked responses</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Good evoked responses</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>Good changes of tremor</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 6. Diagrammatic representations of size and site of lesions in 2 patients superimposed on the presumed anatomy of the region (horizontal section), together with the evoked responses and changes in tremor obtained.

In an attempt to illustrate the findings graphically, the responses were charted on a scale drawing of the presumed anatomy of the surgical site, together with the lesion that was made. Those electrode placements that were used during operation are marked by a cross; those available but not used, are marked with a dot. The center of the square is position O or C. Anterior is toward the top of the diagrams, each successive position being A5, A10, and A15. Similarly, directly posterior from C is P5, followed by P10, P15. Medial, by convention, is to the left, resulting in M5, M10 and M15. Laterally are positions L5, L10 and L15. Positions not lying on the intercepts of the center are labeled as A5 L5, M10 P10, etc.

The estimated size and shape of the lesion is superimposed on the drawing by dashed lines, while the anatomy of the region is suggested by dotted lines. These lines represent the “average” boundaries of the thalamus (and the nucleus ventralis lateralis within), internal capsule and the globus pallidus, according to the atlas of stereotaxy of Schaltenbrand and Bailey.36

For each position used, a fraction indicates the number of positive responses obtained at that point out of the total number of stimuli there delivered. Change of tremor and evoked responses are both listed. At each position the voltages used to elicit the responses are represented on a scale of 15 V. per interelectrode distance on the diagrams.

action. Though it has been stated that the relief of parkinsonian tremor is dependent primarily upon injury to the pyramidal system, the results of the present study are not conclusive in this regard. Although relating the site of the lesion in reference to the sites of stimulation might indicate that many of the lesions that were effective in reducing tremor were located near or in the internal capsule, physical examination showed no definite correlation between signs of a pyramidal-tract lesion opposite to the side operated upon and the results obtained. Moreover, the contrary also obtained, when a good result followed a lesion that was not near the

* These conclusions must be evaluated with caution, since the ages of the two groups, drugs and surgery, were not strictly comparable.
internal capsule according to stereotactic coordinates. Depth stimulation was thus employed in the present study in an effort to locate the ideal site for the lesion and to avoid the errors of anatomy caused by variation in the size of individual brains. The latter point is emphasized by data in which all lesions presumably were "on target," but a) were not followed uniformly by good postoperative results, and b) did not correlate with pyramidal sequelae, that is, lesions presumably in the capsule were not followed by hemiparesis (Y.O.), and others, presumably away from the capsule (H.A.), were effective in producing immediate contralateral paralysis.

It would seem significant that, although the present study constitutes only a preliminary investigation and the number of patients included is relatively small, definite advantages are obtained not only from the objective recording of tremor during surgery but also from the use of the results of depth stimulation as a guide to the site and size of the lesion to be made. There is a theoretical limitation inherent in the use of depth stimulation as a guide to placement of lesions. This limitation is suggested by the somewhat variable results of stimulation, when responses are not always reproducible with the same types of stimuli repeated in the same location. It is not only possible but probable that the tissue surrounding the tip of the electrode does not possess a constant electrical or physiological state. Changes in blood flow, cellular metabolism, etc., may alter impedance or resistance, so that a constant voltage may produce a variable current and a proportionately variable result. Use of bipolar electrodes as well as stimulation by constant current also might offer advantages and we are at present applying the former technique.

Those patients who experienced a good result from operation, not only by clinical examination but also by objective electronic technique, all showed a significant change in tremor, and the latter was not only present, but the lesion included those sites from which change in tremor could be elicited by stimuli-

ation. The specific changes of tremor (parkinsonian type to BCG, or vice versa) did not seem as important as the finding of change in tremor per se. In other words, the very presence of change in tremor in response to stimulation was more important than the specific type of change that obtained. Those patients in whom change in tremor could not be elicited with stimulation, or in whom the lesion did not include those sites from which change in tremor could be elicited, experienced either a poor or questionable result from surgery. This group included those having obtained good motor responses to stimulation, and also lesions which included those areas from which good motor responses could be obtained (Table 2). Good results were obtained in the absence of good motor responses, as long as change in tremor was noted and the lesion included those areas from which change in tremor could be elicited by stimulation. To be sure, 4 patients showed good motor responses and changes in tremor and had lesions that included those areas. Although the present group is small and further study is necessary to verify this assumption, it would seem important to rely not only upon the motor response as a physiologic guide to the site and size of the lesion, but also to consider particularly those sites the stimulation of which is effective in changing tremor.

Summary and Conclusions

1) Ten patients with parkinsonism were treated with lesions presumed to be in the ventrolateral nucleus of the thalamus. Pre- and postoperative evaluation included quantitative electronic measurements of tremor by the accelerometer method, and recordings of this nature were performed during surgery.

2) The value of an objective tremor monitor during surgery is discussed. The use of the lateral ballistocardiogram as an index of normal tremor and as an end-point for the change of tremor during surgery is discussed.

3) It would seem that drugs and surgery attack different mechanisms of production of tremor, while effecting the same results ("less" tremor). Drugs seemed to have a less
specific effect in that the incidence of tremor over a given period of time is reduced; with surgery the actual frequency and amplitude of the tremor are changed toward normal.

4) The importance of physiologic localization, as opposed to the use of coordinates based on anatomical studies alone, is emphasized. In this regard, it would seem important to consider not only the motor responses evoked by stimulation in relation to the position of the internal capsule, etc., but also to consider changes of tremor (for example, parkinsonian to physiologic tremor) as a guide to placement of lesions. From the present preliminary investigation, it would appear that change of tremor is potentially more valuable than evoked or motor responses as an indication for site and size of lesions.

5) Emphasis is placed on the collection of a large body of data, including not only the subjective clinical opinion of the patient, but also a neurologic examination, according to a carefully outlined protocol and also electronic objective measurements of the various parameters involved. Adequate follow-up study and a large number of patients will be necessary to amplify and verify these conclusions.

The authors express their appreciation to Mrs. Irene Borroff for her excellent technical assistance. They also wish to express their thanks and appreciation for the stimulating and unstinting help given during this study by Doctors Benjamin Boshes and Loyal Davis. Our appreciation is also extended to the Boothroyd Foundation for the assistance given in the pursuance of this study.

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