Subthalamotomy in Treatment of Parkinsonian Tremor*

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In the neurosurgical treatment of parkinsonian tremor, a major question to be answered is, where is the optimum site of target for the lesion? The present study is an attempt to evaluate the posterior ventrolateral area of the thalamus, internal capsule, medial region of the globus pallidus and posterior subthalamus. The comparative value of lesions in these structures was determined by (1) noting differences in reduction of tremor associated with insertion of electrodes, and (2) a comparison of the amount of radio-frequency electrical energy (expressed as Bovie-time factor) necessary to obtain over 75 per cent reduction in tremor. The primary objective of this presentation is to demonstrate that lesions in the posterior subthalamus are the most efficient for reducing parkinsonian tremor.

Technique

Patients. From a group of 150 parkinsonian patients with varying degrees of tremor and rigidity, only those patients having unilateral or bilateral tremor as the major finding were utilized for this study. Tremor was bilateral in the majority of the 58 patients although usually it was more pronounced on one side. The mean age of the patients was 58 and ranged from 41 to 80 years. All patients had been receiving a variety of medications before operation which did not satisfactorily control the tremor. Patients with bilateral tremor were replaced on medication postoperatively. Since these observations were made in patients distributed over the past 7 years, the traditionally desired 5-year detailed follow-up was not possible. The shortest period of follow-up was 4 months (3 patients).

Operation. A total of 72 operations were performed in the 58 patients. Bilateral operations were done in 6 patients and in 1 it was repeated. Repeated unilateral operations were performed in 6 and the rest of the patients had unilateral procedures. Operations were done with patients in the supine position. One per cent Xylocaine was used for local anesthesia of the scalp. The patients were not premedicated and remained awake throughout the procedure. A frontal burr hole, ½ inch in diameter, was placed 1½ cm. from the midline and 7½ to 8 cm. posterior to the glabella. A ventriculogram was performed and utilized for calculating coordinate measurements. These were supplemented with preoperative pneumoencephalograms. Roentgen-ray tube-plate distances of 40° were used for both lateral and frontal views. The central beam was directed just above the sella in the lateral view and proper corrections were made for distortions.

Coordinate System of Measurement. Horizontal zero consisted of a plane extending from the mid-posterior margin of the anterior commissure to the anterior margin of the posterior commissure. Frontal zero plane was at a point midway between the anterior and posterior commissure at right angles to the horizontal plane. Sagittal zero plane was identified by a vertical line passing through the center of the 3rd ventricle in the frontal projection. For purposes of this study, the localizations were expressed in terms of the electrode-tip position. However, it must be emphasized that the electrode was oriented in approximately a 40-degree angle with the horizontal zero plane in the sagittal projection.

Radio-frequency Lesions. Lesions were made with the Bovie, a spark-gap generator of radio-frequency current. The current was applied through electrodes insulated up to 4 to 10 mm. from the tip. Four to 5 mm. bare tips were used for subthalamic lesions and 6 to 10 mm. bare tips for lesions of internal capsule, thalamus, and globus pallidus. The diameter of the electrode was slightly over 1 mm. Characteristics of the Bovie in relation to making a lesion were determined in egg white and in 20 cat brains.

Size of Lesion. With a constant size of electrodes, the size of an electrically induced lesion is proportional to two major factors: (1) magnitude and (2) duration of the applied current. For purposes of this study, therefore, the lesion necessary to reduce tremor was expressed in terms of the “Bovie-time factor.” This value was obtained by multiplying the Bovie setting and the duration of the applied current (in seconds). The relation between “Bovie-time factor” and size of the lesion is given under Results. Bovie settings of 7½ to 30 with durations of 5 to 15 sec. were used. In

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most instances, the Bovie setting was varied and the duration of the applied current was maintained at 15 sec. The current was re-applied at 15- to 20-min. intervals until the desired reduction in tremor was obtained. "Bovie-time factors" utilized ranged from 75 to 3,500.

**Evaluations of Tremor.** Evaluation of tremor was made by clinical observation, tremogram recordings and, in some instances, with motion-picture recordings. Exact quantification of the output of tremor by evaluating the tremograms was attempted and was found to be very difficult. Thus, objective, but nonquantitative methods were used to evaluate patterns of tremor, periodicity, amplitude, frequency, persistence, and reaction to stress over time. To observe changes in tremor during insertion of the electrode, the electrode was advanced in increments of 2 to 4 mm. A minimum pause of 15 to 30 sec. was used to evaluate the tremor between each increment of insertion.

*High-frequency Lesions in Cat Brains and Egg Albumin.* Twenty-two cats were used to determine the Bovie characteristics in producing a radio-frequency lesion. A lesion was placed in both hemispheres of each cat and in several cats two small lesions were placed in one hemisphere. Electrode punctures of the brain without coagulation and electrocoagulation without a ground were utilized as controls. One week after lesions were placed animals were sacrificed and the brains were cut serially. To avoid the marked shrinkage of tissue associated with paraffin- and celloidin-embedding techniques, the serial frozen-section technique was used. Transverse diameters of the lesions were then measured directly from the histological sections which were stained with cresyl violet. For purposes of this study, no correction was necessary for shrinkage of tissue since it was relatively small. In addition, 3 cats and egg whites were used to correlate different Bovie settings with output of current. Egg white was used to correlate the size of the coagulum for various Bovie settings and durations necessary to producing bubbling and charring. The graphs present studies done with a 4 mm. bare tip of the electrode (Figs. 1 and 2).

*Sagittal Planes for Presentation of Results.* Results were plotted in sagittal stereotaxic planes for two reasons: (1) the brain stem is narrower than it is long and therefore fewer figures were needed to represent the points of localization and (2) the electrode was oriented at approximately a 40-degree angle with the horizontal zero line, in the sagittal plane, and directed from a frontal approach, 1 1/2 mm. from the midline. The tips of the electrodes were located in sagittal planes 8 mm. through sagittal plane 22 mm. from the midline. Consequently, they were divided into four composite groups as follows: lateral 8.0–10.5 mm., 10.5–13.5 mm., 13.6–17.5 mm., and 17.6–22.0 mm. Each of these composite groups represented widths of 2.5 mm., 3 mm., 4 mm., and 4.4 mm. respectively. The width represented in each group was chosen to allow for one standard deviation in the neuroanatomic variability as described by Van Buren and Maccubbin. Greater variability was allowed for sagittal planes as they progressed further away from the point of reference.

**Statistical Analysis.** Statistical analyses were performed utilizing chi-square and two-tailed t-tests.*

**Results**

*Bovie Output.* Since the Bovie is a spark-gap radio-frequency device, it presents problems in the measurement of its output of power. However, an indication of its output contributing to the development of a lesion was obtained by placing an incandescent lamp in series with the electrode. The light from the lamp was measured photoelectrically and the Bovie output at each setting of power was determined by "calibrating" the lamp with a direct current. Fig. 1 shows the relationship obtained between equivalent DC current and Bovie setting of output. Since power is a function of current, these results indicate an increase in output of power with increased setting of Bovie. The energy dissipated in the tissue is a function of power and time; consequently, we have chosen to relate the lesion to the "Bovie-time factor."

* Our appreciation is expressed to D. Foshee and D. Peeler for their assistance with the statistical analyses.
Bovie Radio-frequency Current in Egg White. Bovie range of 20 to 30 produced bubbling and charring of the egg white within 3 to 5 sec. after application. In contrast, Bovie settings of 10 to 15 required 15 to 20 sec. to produce bubbling. Bovie of 5 to 7.5 did not induce bubbling and charring until well over 1 min. (Fig. 2, graph 1).

The transverse diameters of the egg-white coagulum varied according to the magnitude of the Bovie current applied. With onset of bubbling as the end point of the duration of the current applied, transverse diameters of the coagulum reached 5 to 6 mm. with the lower settings and about 3 mm. with the higher settings (Fig. 2, graph 2). These observations imply that much better control of the size of the lesion can be attained with the lower Bovie settings since they produce a relatively larger lesion over a longer period of time before charring the egg white.

Bovie-Time Factor and Size of Lesion in Cat Brain. A correlation of the size of the lesion with the "Bovie-time factor" suggests a linear relationship within the range of lower values, 75 to 200 (Fig. 2, graph 3). With "Bovie-time factors" less than 200, symmetrical lesions 4.5 to 6 mm. in diameter were observed in the cat. However, Bovie factors above 200 presented no linear relationship and the lesions became larger and asymmetrical. With the 4 mm. bare tip, lesions beyond 6 to 7 mm. in diameter necessitated relatively tremendous increases of the Bovie-time factor. It was so disproportionate that it could not be used to represent relative sizes of the lesions. The relatively small increase in size of the lesion with the very rapid rise of the Bovie-time factor revealed that there was a tremendous amount of energy necessary to increase it appreciably beyond a certain point. Lesions made with Bovie settings and durations of time which would be expected to produce egg-white bubbling, produced brain lesions of unpredictable size (triangles, Fig. 2, graph 3). Note that the Bovie and time-duration values for the triangles in the unpredictable brain-lesion zone (Fig. 2, graph 3) have Bovie and durations of time which when plotted in Fig. 2 lie within the egg-white bubbling and charring zone.

Insertions of Electrodes and Tremor. There was a total of 100 insertions of electrodes in 72 operations. Spontaneous reduction in tremor of 50 per cent or greater lasting 30 to 60 min. was observed only with insertions of the electrode into the subthalamic structures. A similar reduction in tremor was not seen in sagittal planes more lateral than 13.5 mm. There were three insertions in sagittal planes 17.6–22 mm. (represented by three circles in a cluster, Fig. 8) which induced more than 50 per cent reduction in tremor but it was not long-lasting. For statistical comparison, the

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Fig. 2. (Graph 1) Points are plotted according to duration, in seconds, necessary for a given Bovie setting to produce onset of bubbling in egg white. The area above and to right of curve is designated the bubbling and charring zone (diagonal lines). The lines in this and subsequent graphs are used to demonstrate approximate trends. (Graph 2) Points are plotted according to transverse diameter of egg-white coagulum at onset of bubbling for a given Bovie setting. Size of lesion is expressed in mm. (Graph 3) The size of lesion in the cat brain is plotted against the Bovie-time factor utilized. The stippled area to right of vertical line represents zone of unpredictable size of lesion in terms of Bovie-time factor.
Both left and right figures contain points which produced 50 per cent or more reduction in spontaneous tremor during insertion of electrode (black circles), and points that did not produce 50 per cent decrease in tremor (clear circles). The electrodes were inserted in increments of 2–4 mm., in approximately a 40-degree angle with the horizontal zero plane directed from a frontal approach. Frontal zero represents midthalamic point and horizontal zero represents line between center of anterior and posterior commissures. The right side of the figure represents a composite of sagittal planes 10.6–13.5 mm. from midline and left side a composite of 8.0–10.5 mm. from midline. Stippling is used to represent an approximation of areas through which insertion of electrode was not accompanied with 50 per cent or greater reduction of tremor.

Points in the sagittal plane 8–10.5 mm. (Fig. 3) were divided into two groups by erecting a line of separation at a right angle to the direction of the electrode and coursing through the point (Fp 5, H-4.5). The difference was significant to the .01 level (chi square, 8.06). Greater significance is attached to the results when one notes that positive points also represent insertion of electrode through more dorsally located thalamic structures which were not effective in reducing tremor (stippled area, Fig. 3). It is of interest to note that tips of the needle designating positive points in the subthalamus of sagittal planes 8–10.5 (Fig. 3) were clustered within a small area extending from Fp 5 to Fp 12 longitudinally and H-2 to H-6 vertically.

Points in sagittal plane 10.6–13.5 also were divided into two groups by a line perpendicular to the direction of insertion of electrode and coursing through the point (Fp 5, H-4.0). The difference between the two groups was not significant in this composite sagittal plane. However, it should be noted that positive points, although scattered, were located predominantly below the horizontal zero line and behind the midthalamic point.

In some instances a reduction in tremor was first noticed at a level 2 to 4 mm. above the final depth, but the reductions in tremor were not as pronounced nor as long-lasting as at the final or greater depth. In some instances, insertion of electrode 10.6–13.5 mm. lateral to the midline, and coursing below horizontal zero, tended to accentuate the fast components of the tremor. Removal of the electrode and reinsertion in a more medial sagittal plane usually was accompanied by a very significant diminution of the tremor (Fig. 4). It also should be noted that although the spontaneous reduction in tremor may be greater than 75 per cent following the introduction of the electrode, it may be reactivated by inducing some form of “stress” such as having the patient count. If the “stress” produced a significant return of the tremor the electrode was inserted a little deeper and the activation previously associated with counting was reduced further or abolished (Fig. 4). Several patients not included in this report had electrodes inserted in more anterior subthalamic structures and no reduction in tremor was observed.

In 12 patients, the electrode was reinserted a second time before reduction in tremor was obtained (Table 1). Note that 6 of the non-effective insertions were located medial to sagittal plane 8 mm. Among the 12 effective insertions, 7 were located within sagittal planes 8.0 to 10.5 mm. from the midline. The question arises as to whether the first insertion of the electrode influenced the results of the second. The probability is that very little
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The top and bottom illustrations represent two independent insertions of electrodes performed during same operation. (Top) The first insertion at sagittal plane 18.5 was associated with no reduction in tremor. (Bottom) The second insertion was made in sagittal plane 9 mm. and was accompanied by more than 75 per cent reduction in tremor. Stress indicates attempts to activate tremor by having the patient count. See text for further details. Diagrammatic illustration of diencephalon was obtained from stereotaxic atlas of Schaltenbrand and Bailey. 22

if any influence persisted since the changes following the second insertion usually occurred abruptly and in the last 2 to 4 mm. of advancement of electrode. In 4 patients, L.H., W.M., J. Be., and P.A., increased amplitude of tremor developed following the first insertion (Table 1). The second insertion was effective in abolishing the tremor except for L.H. and J. Be., in whom the improvement was not well sustained.

"Bovie-Time Factor" and Efficiency of Reduction in Tremor. In sagittal planes 8–10.5 mm. and 10.6–13.5 mm. from the midline, below the horizontal zero and behind Fp 3, reductions in tremor of 75 per cent or greater were produced with relatively low "Bovie-time factors" (Fig. 5). Using the actual "Bovie-time factor" values revealed in sagittal planes 8–10.5 mm. the points in the nonstippled group to be significantly different from those in the stippled group at the .05 level (t = 2.66, df = 9). Note that lesions necessitating relatively large Bovie-time factors were located along the border of the more efficient site of lesion. Of greater significance is a comparison with the sites that were not associated with reduction in tremor of 75 per cent even with relatively very high Bovie-time factors. These were located even further away from the optimum site of lesion.

In the sagittal plane 13.6–17.5 Bovie-time factors effective for a 75 per cent reduction in tremor in most cases necessitated values above 799 (Fig. 6). Out of the 11 points in this area only 2 had effective reduction in tremor with less than 400 "Bovie-time factor" value. In sagittal plane 17.6–22.0 mm., 4 out of the 5 effective points necessitated Bovie-time factors above 799 (Fig. 6). In contrast to the two composite planes located more medially (Fig. 5), in the thalamus and subthalamus, the lesions situated more laterally obviously were much less efficient in producing a significant reduction in tremor.

Recurrence of Tremor and Reoperation. A 75 per cent improvement in tremor which was sustained for 3 months usually remained at about the same level of improvement in the following years. In most cases lesions that were not effective in maintaining a 75 per cent improvement became evident within 2 to 3 weeks after the operation. Among the patients who did not maintain the 75 per cent improvement, only 6 had repeated operations within 3 to 6 months after the first procedure. Effective reduction was obtained in all but 1, in which the second lesion was capsular. The first operations did not involve

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FIG. 5. Sites of lesions produced with radio-frequency currents are collected in two composite figures, sagittal planes 8.0–10.5 mm. on left and 10.6–13.5 mm. on right. Sites are designated by symbols representing Bovie-time factor necessary to induce 75 per cent or more reduction of tremor (black figures) and those sites in which 75 per cent reduction of tremor was not obtained (empty figures). It should be recalled that the indicated points of localization correspond to tip of electrode. Lesions in nonstippled area of sagittal plane 8.0–10.5 mm., below horizontal zero and posterior to Fp 3, were made with 4 mm. bare tip of electrodes. Lesions in stippled area were made with tips of electrodes ranging from 6–10 mm. in length. For sagittal plane 10.6–13.5 mm. most lesions in white area were made with tips of electrodes 5–6 mm. in length and those in stippled area with tips 6–10 mm. The empty square and triangle in nonstippled area of sagittal plane 8–10.5 mm. represent a double lesion placed at same operation. In sagittal planes 10.6–13.5 there are 3 double lesions represented. (The first was ineffective at same operation.) The double lesions that go together are the hexagon (bordering the stippled-nonstippled area) and the large square at Fp 7.5, H-4, the large empty and black circles in nonstippled area, and the small empty square in nonstippled and the small black square located at Fp 8, H-3.

Lesions in these cases were all located lateral to sagittal plane 10.5. No hemiparesis or hemianopsia occurred. All patients with bilateral operations became less interested in their environment and had lost a great deal of spontaneity and initiative. The change in personality appeared to persist for several years and was difficult to overcome even with medication. Lesions in the bilaterally operated group primarily have been lateral to subthalamic structures. Improvements following the second operations were associated with lesions implicating the subthalamus in 4 patients and very extensive lesions in the globus pallidus in 1 patient.

Postoperative Complications. Contralateral weakness and limping were observed in 5 patients to last over 2 years. The impairment, however, has been minimal and has not necessitated crutches or braces. The lesions in these cases were all located lateral to sagittal plane 10.5. No hemiparesis or hemianopsia occurred. All patients with bilateral operations became less interested in their environment and had lost a great deal of spontaneity and initiative. The change in personality appeared to persist for several years and was difficult to overcome even with medication. Lesions in the bilaterally operated group primarily have been lateral to

FIG. 6. Radio-frequency lesions in composite sagittal planes 17.6–22.0 mm. (left) and sagittal planes 13.6–17.5 (right) were made with bare tips of electrodes 6 to 10 mm. in length. See Fig. 7 for other details. The inverted V point of insertion of electrode not associated with reduction in tremor. The two points at Fp 1.5, H-1.5, and Fp 3, H-3.5 represent a double lesion.
sagittal plane 10.5. The 1 patient with bilateral subthalamic lesions has not had any tremor for 2 years. After the second operation, she had a jovial, carefree attitude in contrast to her preoperative tendency to worry and be apprehensive. At first she walked as if all extremities were limp and flail and displayed dysarthria.

Over one-third of the patients manifested an increased desire for food. In some patients, this was observed immediately postoperatively. Some of the patients and their family actually complained about constantly wanting to eat and not being satisfied. This complication has remained for several years and some of the patients actually have become obese. It has developed after unilateral and bilateral operations and has occurred with lesions placed in all four of the sagittal planes described. Polydipsia is not an accompaniment of this complication. Relatively short-lasting complications occurred such as ipsilateral ptosis, partial contralateral facial paresis, depression, agnosia, and ataxia with leaning toward the contralateral side of the operation. These complications may last for 1 to several weeks postoperatively and occurred with lesions placed in all of the sagittal planes described. Five patients had ballism postoperatively. In 2 patients, it stopped after 2 months; in the others, it stopped within the first week postoperatively. These occurred with lesions that were placed lateral to sagittal plane 10.5 mm. It should be noted that undoubtedly there are many lesions within sagittal planes 8-13.5 ventral to the horizontal zero plane, that implicate the subthalamic nucleus and no corresponding number of complications with ballism developed. Lesions placed in sagittal planes 8-10.5, below horizontal zero and behind frontal plane Fp 2, were not accompanied by marked depression. This, in part, may be ascribed to the lesions being smaller in this area. Most of the patients with lesions within sagittal planes 8–10.5 were ambulatory within 24 hours after operation. Permanent sensory deficits have not been observed. However, a subjective complaint of numbness around the mouth and occasionally in the tips of the fingers has occurred in several patients and in 2 patients it has persisted for over a year, although decreased in severity. No objective changes can be detected with pinprick, touch, and two-point discrimination over the areas of numbness. The subjective complaint of numbness as described occurred primarily with lesions placed posterior ventrally in the sagittal planes 8–10.5. It should be noted that ataxia has not been as marked a complication with lesions in the sagittal plane 8–10.5 and ventral to horizontal zero and posterior to Fp 2. It has been a little more pronounced with lesions located more dorsally.

Discussion

In view of our objective, it first was thought necessary to discuss the two major criteria employed to demonstrate that lesions in the subthalamus were the most efficient in reducing parkinsonian tremor. Reduction in tremor coincident with penetration of a structure, by an electrode, was one criterion. A lesion, no matter how small, always is produced by an electrode as it penetrates tissue. The volume of tissue damage induced in a given structure is a function of the diameter of the electrode and the distance it penetrates the tissue. The size of the lesion thus would depend upon the diameter of the electrode and the increments of insertion. In this instance, the diameter was slightly over 1 mm. and the increments of insertion were 2 to 4 mm. In the area of the brain stem with which we are concerned, lesions of this magnitude appeared to be adequate to differentially evaluate various areas with respect to their influence on tremor. The next question one may ask is whether or not the temporary change in reduction of tremor seen with such a small lesion is significant as a guide for placement of a larger and more permanent lesion to reduce the tremor. According to the results, it does appear to be a significant guide.

The second criterion for determining efficiency of the lesion was based upon determining the relative amounts of radio-frequency current necessary to produce a
lesion, which would reduce tremor a given amount. Since the size of the lesions depended upon the magnitude and the duration of the current applied, the product of these two values ("Bovie-time factor") was used as a relative indicator of the efficiency. The correlation between size of the lesion and "Bovie-time factor" was found to be roughly linear with "Bovie-time" values below ~0.0, but not with higher values.

The heterogeneity of the population group was of concern to us in a study of this type. No two patients were found to have exactly similar patterns of tremor and similar degrees of severity. Most patients had bilateral tremor, although the changes usually were greater on one side. There was a large variation in the age range of the patients. The shortest postoperative period was 4 months, in 3 patients, in contrast to several years, in most patients. Based on the probability that we are dealing primarily with a similar fundamental problem in most cases, in spite of the differences mentioned, it appeared justifiable to lump the patients together, in one group, for a broad evaluation. In so doing, it was thought possible to at least obtain an impression as to which areas of the diencephalon to locate a lesion to most efficiently abolish tremor with minimal complications. It was hoped that others will attempt similar comparison with much more sophisticated techniques.

There also was concern with respect to the accuracy of evaluating reduction of tremor, which was based primarily upon the experience and judgment of the investigators. It should be stated that among the patients included in the group with 50 per cent reduction in tremor following insertion of the electrode, the majority were estimated to have had at least 80 to 100 per cent reduction in the tremor. Within the group of patients responding with greater than 75 per cent reduction in tremor following a lesion, the majority actually were estimated to have had at least 90–100 per cent reduction. In most instances, therefore, the reduction in tremor actually estimated was definitely greater than the values utilized to describe and identify the two groups. The actual estimates were not used in order to avoid the human pitfall of overestimating the percentage of beneficial response to a procedure and to lean toward conservative estimates.

It may be asked, why should one artificially separate the brain-stem areas studied, into four composite divisions ranging from 2.5 to 4 mm. in thickness with the smallest being the most medially located. This was done on the basis of accepting a variability in localization among brain-stem structures, of one standard deviation, according to the studies of Van Buren and Maccubbin. This means that if one desired to hit a target midway between 8 and 10.5 in the sagittal plane, a minimum lesion of 2.5 mm. in diameter will successfully implicate the desired structure in 68 per cent of the cases.

It may be inferred from the data that the relative difference in efficiency to reduce tremor may, in part, be associated with relative differences in the size of the lesion. Let us assume that we have determined the optimum site for placement of the smallest lesion to obtain a given amount of reduction in tremor. We can then assume that lesions located in the periphery of the optimum site would have to be larger in order to obtain a similar degree of improvement. For the peripheral lesions, the necessary enlargement in size would be a function of its distance from the optimum site. As one progresses further away from the target, the lesions would become ineffective if they were not large enough to encompass upon the optimum site. A plot of the "Bovie-time factors" as illustrated in Fig. 7, progressing from the non-stippled into the stippled areas, revealed a transition from an area of relatively small "Bovie-time factors" which were effective, through a border in which large "Bovie-time factors" were needed to be effective, and beyond this, to an outer border in which even the large "Bovie-time factors" were no longer effective. This relationship between the optimum site and the periphery appears to satisfy the argument that size and location of the lesion are both important.

It is difficult to determine whether or not
lesions located in the nonstippled area of composite sagittal section 8.0-10.5 mm. are more efficient than lesions located in the nonstippled area of composite sagittal section 10.6-13.5 mm. (Fig. 7). The two factors contributing to this difficulty are (1) lack of a statistical difference between the “Bovie-time factors” used for each of the groups and (2) the probability that the smallest lesions, 4 to 6 mm. in diameter, when placed in one sagittal group may in reality actually overlap and implicate the other group (each of the two groups represents 2½ and 3 mm. thickness of tissue). However, the results from reduction in tremor following insertion of electrode indicate that the best target for the most efficient lesion lies in the sagittal planes 8.0-10.5 mm. rather than 10.6-13.5 mm. from the midline. In view of these observations, one cannot avoid the temptation of correlating the optimum site thus obtained with the specific brain structures in those areas (Fig. 7). Although variabilities in relationships of brain structures have been demonstrated adequately and emphasized,1,2,3,7,13,14,16,17,21,24,28,29 the various available atlases reveal enough consistencies,22,23,27,29 so that approximations between a set of coordinates with a specific structure or structures are adequate for our present needs. With reference to the various atlases available, it appeared that the optimum site for the most efficient lesion corresponds to the posterior subthalamus which includes the field H of Forel, the zona incerta, and the prerubral field medial to the subthalamic nucleus. For three-dimensional visualization, an isometric representation of the optimum site was constructed, based on changes in tremor during insertion of electrodes (Fig. 8).

These studies shed no light as to whether the effectiveness of a subthalamic lesion is the result of interruption of impulses projecting upon the lower motor neurons via the cortex10,15 or whether it is implication of efferent systems which project to lower brain-stem18,25,26,31,32 and spinal-cord structures without necessarily implicating the cortex. Both mechanisms obviously are implicated. It is of importance to note that

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Fig. 7. The most efficient site for a lesion to reduce parkinsonian tremor is outlined by a white line in 6 representative frontal brain sections. Sections are from atlas of Schaltenbrand and Bailey.21
lesions in posterior subthalamus do not tend to induce ballism even if they implicate the subthalamic nucleus.\textsuperscript{8,4} Lesions in this area may be more effective than those in the globus pallidus for reducing tremor resulting from lesions in the subthalamic nucleus, in the monkey.\textsuperscript{8–12}

**Summary**

Fifty-eight patients underwent 72 diencephalic operations for the treatment of parkinsonian tremor. The Bovie, a spark-gap radio-frequency generator, was used to make the brain lesions. The “Bovie-time factor” was used as a measure to evaluate the relative efficiency of lesions induced by radio-frequency current to reduce tremor 75 per cent or more. The “Bovie-time factor” represented the product of the Bovie setting and the duration of the applied current. The characteristics of the lesions induced by Bovie radio-frequency were studied in cat-brain and egg-white preparations.

**Cat-Brain and Egg-White Studies.** (1) According to cat-brain and egg-white studies, the size of a lesion tends to be linear in relation to the “Bovie-time factor” values of less than 200. Lesions produced with “Bovie-time factors” above 200 were unpredictable in size and shape and presented no readily definable relationship.

(2) Based upon the cat-brain and egg-white studies, it was inferred that lesions of 4 to 6 mm. in diameter were produced with “Bovie-time factors” less than 200. A Bovie setting of 5 to 10 provided the optimum control in producing a symmetrical lesion 4 to 6 mm. in diameter without charring.

**Patient Studies.** (1) For purposes of this analysis, the diencephalic areas evaluated were divided into four composite sagittal planes extending from lateral 8 through lateral 22 mm. from the midline. The positions of electrodes were identified according to the coordinate localizations of the tips of the electrodes.

(2) The efficiency of a lesion to reduce tremor, a given amount, was determined by (a) evaluating the mechanical effect of insertion of the electrode and (b) evaluating the relative amount of radio-frequency energy necessary to produce a lesion that reduced tremor a given amount.

(3) Based upon correlating our data with the various stereotaxic atlases available, it was concluded that the optimum area for the most efficient lesion was in the posterior subthalamus and included the field H of Forel, zona incerta, and the prerubral field medial to the subthalamic nuclei.

(4) Both the short- and long-lasting complications following lesions placed in the optimum site of the subthalamus were not as pronounced as those associated with lesions in other areas studied.

**References**


4. ANDY, O. J., and BROWNE, J. S. Diencephalic


