Stereotactic ventrolateralis thalamotomy for medically refractory tremor in post-levodopa era Parkinson’s disease patients

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Thirty-six patients with Parkinson’s disease and medically refractory tremor underwent stereotactic ventrolateralis thalamotomy at the Mayo Clinic between 1984 and 1989. All patients had been or were being treated with carbidopa/levodopa but with unsatisfactory tremor control. Modern stereotactic techniques, including microelectrode recording, were used to treat 36 patients, of whom 31 (86%) had complete abolition of tremor and three patients (5%) had significant improvement. Tremor recurred in two patients within 3 months of surgery; however, the remaining patients suffered no recurrence of tremor during follow-up periods ranging from 14 to 68 months (mean 33 months). Persistent complications (arm dyspraxia, dysarthria, dysphasia, or abulia) were noted in five patients but were a source of disability in only two. It is concluded that thalamotomy in carefully selected patients is a beneficial operation for the control of medically refractory parkinsonian resting tremor.

Key Words • operative technique • thalamotomy • Parkinson’s disease • tremor

Parkinson’s disease is irreversible, progressive, and characterized by resting tremor, rigidity, bradykinesia, and postural instability. In the pre-levodopa era, stereotactic thalamotomy was one of the few alternatives for treating this condition. With the advent of levodopa and related medications, thalamotomy was almost abandoned as treatment for parkinsonian tremor. This waning enthusiasm for thalamotomy was, in part, related to its somewhat inconsistent results and complications associated with earlier stereotactic surgical techniques. Unfortunately, not all patients with Parkinson’s disease experience an optimum response to medications. Consequently, there remains a role for surgical treatment of parkinsonian tremor.

Stereotactic operative techniques have improved significantly during the last decade due to improved instrumentation and methods for electrophysiological monitoring, and to the introduction of computerized tomography (CT). Indeed, modern CT-based stereotactic procedures have altered the neurosurgical management of many intracranial conditions. Moreoever, intraoperative electrophysiological monitoring has further increased the precision of stereotactic surgery in general, and specifically of thalamotomy for control of movement disorders.

Patients are now referred for thalamotomy later in the course of their disease, often following several years of carbidopa/levodopa therapy. Thus, comparison between contemporary results and those reported for patients operated on in the pre-levodopa era may not be valid. The improved precision of modern thalamotomy has helped to maximize therapeutic benefits and minimize complications in patients who, in the past, may have had poorer postoperative results and higher morbidity.

This report documents the surgical results and complications in a carefully studied series of contemporary patients undergoing thalamotomy for control of medically refractory parkinsonian rest tremor. All patients had the benefit of stereotactic thalamotomy performed with a computer-assisted technique with microelectrode recording control.

Clinical Material and Methods

Clinical Evaluation

Before and after thalamotomy, each patient underwent a careful neurological examination, as well as speech and language evaluation by a speech pathologist. Audiotape recording of each patient’s speech was performed before, during, and after surgery. Cognition
was evaluated by pre- and postoperative psychometric testing.

**Surgical Procedure**

The method for stereotactic ventrolateral thalamotomy with microelectrode recording control and the instrumentation used in these procedures have been described in detail and illustrated elsewhere. The procedure was performed in two sessions, consisting of a data acquisition procedure, during which stereotactic CT scanning and ventriculography were performed to identify the approximate location of thalamic subnuclei, and semi-microelectrode recording for subnuclear definition and determination of the correct lateral positioning prior to production of a radiofrequency lesion.

**Data Acquisition.** Patients underwent stereotactic CT scanning with their head fixed in a CT-compatible stereotactic headholder. The CT localization system produced nine reference marks on each CT slice which allowed calculation of stereotactic coordinates. The CT scan indicated the axial configuration of the third ventricle, the thalamus, and the location of the thalamocapsular boundary.

A stereotactic positive-contrast ventriculogram was performed in each patient through a coronal burr hole utilizing a No. 5 French pediatric feeding tube and 3 to 4 cc of 220 mg% concentration of metrizamide directed stereotactically to the foramen of Monro. The position of the anterior and posterior commissures was identified on anteroposterior and lateral teleradiographs. The presumed position of the subnuclei of the ventralis lateralis nuclear mass was inscribed on the ventriculogram radiograph utilizing the method described by Guiot and coworkers.

**Semi-Microelectrode Recording.** A bipolar concentric microelectrode with a 10- to 50-μm active recording tip, and a 400-μm tip-to-ring distance was directed from the coronal burr hole to a target point 1 mm anterior to the posterior commissure on the anteroposterior commissure line, and 11.5 to 13 mm lateral to the lateral wall of the third ventricle. The cellular electrical activity was monitored both on an oscilloscope and aurally. Cellular electrical activity was encountered at the cortex, the caudate nucleus, and the dorsal and ventralis posterior nuclear groups. High amplitude (150 μv) sensory evoked responses were obtained by touching the body part corresponding to the topographic representation within the region of ventralis posterior in which the microelectrode tip lay. One or more microelectrode trajectories were used to establish the medial and lateral somatotopic organization within the ventralis posterior in individual patients. This information was used as a physiological landmark to determine the proper lesioning position within the nucleus ventralis lateralis located immediately anterior to the nucleus ventralis posterior.

In addition, median and tibial nerve somatosensory evoked responses recorded from the semi-microelectrode were used to identify the electrophysiological inferior boundary of the ventralis posterior (this corresponds to the inferior boundary of the thalamus) by observing the reversal of polarity of the N_1 wave as the electrode passes from the ventralis posterior into the medial lemniscus. At this point, anteroposterior and lateral teleradiographs documented the position of the electrode tip. The final height, or z-coordinate, for the lesion center within the ventralis lateralis target was 2.5 mm above the inferior boundary to the thalamus.

The y-coordinate for the target point was at the junction of the ventralis oralis posterior and ventralis intermedius on the ventriculogram, with a lateral position (x-coordinate) determined from the microelectrode recordings as follows. For the treatment of upper-extremity tremor, lesions were made in the ventralis lateralis anterior to the ventralis posterior representation of the thumb or index finger. For treatment of lower-extremity tremor, the lesion was made more lateral, anterior to the ventralis posterior representation of the fifth digit.

**Lesioning Procedure.** The 1.1- or 1.6-mm diameter lesioning/stimulating probe was inserted to the target point where low (2 to 3 Hz) or high (100 Hz) stimulation at threshold usually augments or reduces tremor, respectively. Radiofrequency lesions were made with a temperature-monitored electrode 1.1 to 1.6 mm in diameter with a 4-mm exposed tip. Patients received a test lesion of 42°C for 60 seconds and the effects on contralateral tremor, strength, coordination, speech, and memory were noted. A speech pathologist was present in the operating room to look for signs of dysarthria or dysphasia in patients undergoing dominant-hemisphere thalamotomy or the second side of bilateral thalamotomies, as well as in those with preoperative speech and language problems. If no untoward neurological deficits were observed, an irreversible lesion was made by heating the electrode tip to 70°C to 78°C for 60 seconds. After lesioning, the patient's neurological status was again assessed. If the patient had residual tremor and no motor, speech, or cognitive side effects were noted, the lesion was enlarged 2 to 3 mm dorsally for proximal arm tremor, 1 to 2 mm more laterally for ulnar deviation tremor, or further laterally (anterior to the ventralis posterior representation of the fifth digit) for lower-extremity tremor. The patient was examined on the operating table after each lesion. Further lesioning was aborted if reduced voice volume, speech imprecision, dysphasia, or weakness was encountered.

**Follow-Up Procedure**

Follow-up evaluations were performed prior to discharge from the hospital, and in most cases at 3 and 12 months, and annually thereafter when possible. For those patients unable to travel to the Mayo Clinic, follow-up telephone contact was made for purposes of this review. Evaluations included a neurological exam.
Stereotactic thalamotomy for parkinsonian tremor

TABLE 1
Preoperative clinical characteristics of 36 patients with Parkinson's disease undergoing thalamotomy

<table>
<thead>
<tr>
<th>Feature</th>
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<td>patient age (yrs)</td>
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<td>range</td>
<td>30–72</td>
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<td>duration of symptoms (yrs)</td>
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<td>upper-extremity tremor</td>
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<td>rest</td>
<td>36</td>
</tr>
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<td>16/20</td>
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<td>gait disturbance</td>
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<td>postural instability</td>
<td>15</td>
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<tr>
<td>memory/cognitive deficits</td>
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Results

Thirty-six patients underwent 37 stereotactic thalamotomies at the Mayo Clinic for control of medically refractory parkinsonian resting tremor between September, 1984, and July, 1989. Tables 1 and 2 summarize the clinical characteristics in these patients. The average follow-up period was 33 months (range 14 to 68 months).

Twenty-six patients had predominantly right-sided symptoms and underwent left ventralis lateralis thalamotomy, while nine patients had mainly left-sided symptoms and underwent a right ventralis lateralis thalamotomy. One patient underwent bilateral thalamotomy with the right-sided procedure performed 1 1/2 years following the left-sided operation. All patients had moderate to severe resting tremor preoperatively, with the great majority of patients exhibiting a combination of resting, postural, and action tremor. Twenty-seven of 36 patients had bilateral limb involvement. In all 36 patients, the resting tremor was the most prominent tremor component and the reason they sought a surgical opinion.

Carbidopa/levodopa (Sinemet) had been used by all but three patients prior to thalamotomy. Two patients were unable to tolerate any anti-Parkinson's disease medications due to side effects, and one patient was receiving multiple medications excluding Sinemet. Of 36 patients, 20 were receiving Sinemet alone and 13 were taking Sinemet plus other drugs (anticholinergic agents, amantadine, bromocriptine, and/or pergolide). The average daily dose of levodopa in the form of Sinemet was 1200 mg/day. Nineteen patients were taking less than 1000 mg/day of Sinemet, 10 patients between 1000 and 1900 mg/day, and eight patients greater than 2000 mg/day for control of their Parkinson's symptoms.

None of the patients experienced satisfactory control of tremor with their medication. Four patients reported that their tremor had never improved with Sinemet, while 17 patients had a good initial response but subsequent loss of efficacy in controlling their tremor. Thirty-two patients had side effects from their medications including drug-induced dyskinesias in 16 patients, nausea in eight patients, and drowsiness in four patients. Twenty patients were unable to increase their Sinemet dosage to improve tremor control due to side effects. Ten patients had to take Sinemet every 60 to 90 minutes for tremor control.

Tremor Response to Thalamotomy

At the time of hospital discharge, 34 of 36 patients (35 of 37 thalamotomies) had complete abolition of their contralateral upper-extremity tremor. Of the two patients who did not experience complete postoperative resolution, tremor was significantly diminished in one and unchanged in the other. At the 3-month follow-up examination, 31 of 36 patients had no tremor, and tremor was significantly less than preoperative levels in an additional three patients; tremor in the remaining two patients was essentially unchanged from preoperative levels (Fig. 1).

Twenty-nine of 34 patients evaluated 1 year following surgery had no upper-extremity tremor contralateral to the thalamotomy. A 2-year follow-up examination was available in 22 patients; 18 of these had no tremor. Thirteen of the 16 patients followed for 3 or more years have no tremor. The five patients with recurrent tremor at 3 months continued to have tremor; three remained significantly improved, whereas the tremor in the other two was unchanged from their preoperative state (Fig. 1). All patients with recurrent tremor had recurrence within 3 months of surgery.

Postoperative Medication

Postoperatively, eight patients were able to eliminate medications for the tremor entirely, and seven were
taking reduced doses (average follow-up period 33 months, range 14 to 68 months). Fourteen patients continued to receive their preoperative medication doses and seven reestablished Sinemet or other medications for Parkinson's disease within 2 years of surgery to control other manifestations including dyskinesia or tremor on their nonoperated side.

Morbidity

Persistent Complications. Persistent complications following stereotactic thalamotomy are shown in Table 3. One 61-year-old woman developed dominant upper-extremity dyspraxia following left-sided thalamotomy. In this patient an unusually large lesion in the mediodorsal plane had been made in an attempt to control severe upper- and lower-extremity tremor. The patient does have use of her tremor-free right arm but must use her left arm and hand for fine motor activities. One additional patient had slight dyspraxia of her tremor-free arm which was not disabling, while another exhibited mild hyperreflexia of his tremor-free arm on careful examination but was unaware of any weakness (Table 3).

Three patients developed mild speech/language deficits following left-sided thalamotomy which were detected on formal speech evaluation. These included slight worsening of a preoperative hypokinetic dysarthria in one patient and a new mild spastic dysarthria in another. One patient developed a new mild expressive dysphasia secondary to probe tract hematoma encountered during thalamotomy. At follow-up examination, his expressive dysphasia had partially improved, although he was found to have mild memory and learning difficulties documented by postoperative neuropsychological testing (Table 3).

One 59-year-old patient with severe bradykinetic Parkinson's disease (Hoehn and Yahr stage IV) who was cared for in a nursing home required hourly doses of Sinemet and also experienced incapacitating Sinemet-induced generalized dyskinesias; he underwent left ventralis lateralis thalamotomy for control of tremor and dyskinesias. Preoperative CT scans demonstrated severe generalized atrophy, and preoperative neuropsychological evaluation revealed moderate cognitive impairment. He was abulic following surgery and continued to demonstrate marked cognitive impairment when evaluated 1 month postoperatively. This patient was lost to follow-up review until recent contact with his physician revealed that his preoperative drug-induced dyskinesias and contralateral tremor were absent, and that his behavioral/cognitive state had improved to baseline; however, his Parkinson's disease had progressed.

Transient Side Effects. In the initial postoperative period, some temporary neurological deficits were observed, presumably due to perilesional edema. All of these deficits resolved as the edema resolved and were absent at the patients' 3-month follow-up examination. Tabulation of these transient side effects is shown in Table 3.

Twenty-two of 36 patients had new or worsened neurological findings immediately following thalamotomy (16 left ventralis lateralis surgery and six right ventralis lateralis surgery). These included two patients with worsening of preoperatively noted cognitive deficits, and three others without preoperative cognitive difficulties who experienced mild disorientation and/or somnolence following surgery. All of these findings had cleared by the time of discharge from the hospital. In addition, there were two patients with new and three with worsened hypokinetic dystarthis which had all resolved by 3 months. These patients had undergone left ventralis lateralis thalamotomy.

The most common transient side effect was contralateral central facial weakness, which was observed in 10 patients. On careful neurological examination, seven patients had evidence of slight arm or hand weakness following thalamotomy. Three other patients had mild dyspraxia of their tremor-free arm. Two patients complained postoperatively of numbness of their contralateral hand. Approximately one-half of these side effects had resolved by hospital discharge (average 5 to 7 days). All of these findings were absent by the first follow-up visit at 3 months.

Finally, three patients had complications related to positive-contrast ventriculography. These included a single generalized seizure in one and disorientation and confusion in two patients. All cleared within 3 days.

Discussion

Tremor Control

For the control of tremor, surgeons have created lesions in the motor cortex,\textsuperscript{1,26} ansa lenticularis,\textsuperscript{15,42} thalamic fasciculus,\textsuperscript{55} globus pallidus,\textsuperscript{12,18} and ventro-
### Stereotactic thalamotomy for parkinsonian tremor

**TABLE 3**

*Transient side effects and permanent complications of thalamotomy in 36 Parkinson’s disease patients*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Dominant Hand</th>
<th>Hoehn &amp; Yahr Stage</th>
<th>Side of Lesion</th>
<th>Preop Tremor</th>
<th>Postop Tremor</th>
<th>Intraop Changes</th>
<th>Transient Side Effects</th>
<th>Permanent Complications</th>
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<td>lt</td>
<td>4+</td>
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<td>36</td>
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*Transient = lasting < 2 months; permanent = present at last follow-up examination. 4+ = severe; 3+ = moderate; 2+ = mild; 1+ = slight; 0 = none.
† Worsening of preoperative condition, nondisabling.
‡ Condition disabling to patient.

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Laitinen found that most stereotactic neurosurgeons prefer the ventralis lateralis nucleus as the ideal target site that will interrupt both the extrapyramidal and cerebellar afferent input influencing tremor and rigidity. In general, more anterior lesions within ventralis lateralis preferentially destroy the termination site of pallidofugal fibers and tend to be more effective therapy for rigidity. More posterior lesions preferentially affect the cerebellar afferents to the ventralis lateralis thalamus and are more effective in alleviating tremor.

We believe that CT-based stereotactic thalamotomy with microelectrode recording control allows more precise thalamic subnuclear identification and lesion production for relief of tremor. Smaller lesions within the thalamus should be associated with fewer complications than noted with the larger lesions used in the past. However, postoperative surgical complica-
tions following thalamotomy are in part related to patient age and general neurological status. Even though the best surgical candidates for stereotactic thalamotomy are young patients with unilateral tremor and no evidence of dementia, speech, or gait disturbance, these patients are rarely referred for thalamotomy since most patients experience at least partial tremor control with carbidopa/levodopa. In our experience most of the patients referred for thalamotomy are over 60 years of age with moderately advanced Parkinson's disease. These patients are at a higher risk for postoperative problems. Therefore, we have made it a policy to document carefully pre- and postoperative speech, language, and cognitive function, in addition to the neuro- logical assessment in an effort to monitor complications closely.

The results reported in this paper demonstrate that tremor relief in chronic levodopa-refractory Parkinson's patients can be reliably achieved with modern stereotactic thalamotomy. Abolition of tremor occurred in 31 of our 36 patients with significant improvement of tremor in an additional three patients. These results are consistent with those reported by others from series accumulated in the pre-carbidopa/levodopa era and provide additional support for thalamotomy as treatment for medically refractory tremor. In addition, two closely monitored patients had significant improvement of their preoperative drug-induced dyskinesias. Others have also suggested that thalamotomy seems to protect against dyskinesias of the tremor-free limb in patients who continued taking Sinemet for rigidity, bradykinesia, or contralateral tremor.

Complications

Lesion Placement. Accurate positioning of lesions within the ventralis lateralis nucleus is critical for effective surgical results and avoidance of complications. Complications are usually related to incorrectly placed lesions or unnecessarily large lesions. A lesion placed too laterally within the ventralis lateralis nucleus may result in contralateral hemiparesis due to involvement of the posterior limb of the internal capsule. Too posterior a lesion may result in contralateral hemisensory deficits or dysesthesias due to involvement of the ventralis posterior nucleus. Postoperative hemiballisms may occur in the contralateral limb due to inferior extension of the lesion to the subthalamic area. A lesion placed too medially, especially if bilateral, may affect the fornices and result in memory difficulties. Occasionally patients have developed contralateral neglect or limb dyspraxia despite the abolition of tremor and the maintenance of full strength and sensation. This may be due to interruption of frontal thalamic fibers, or striatopallidothalamic system involvement. Balance and gait difficulty may occur and may at least partially reflect disruption of dentatothalamic projections. Many of these deficits are transient, and may be due to edema surrounding the acute lesion. Table 3 summarizes the transient side effects and permanent complications that occurred in patients in this review.

Hemorrhage. Hemorrhage at the lesion site can also lead to surgical morbidity. Hypertensive patients run an increased risk of lesion site hemorrhage, and perioperative blood pressure control is essential. No patient in this series had perioperative thalamic hemorrhage.

Speech and Language Deficits. Both speech and language deficits following thalamotomy are reported to be common. Mapping studies have shown that speech can be reproducibly altered by electrical stimulation within the ventralis lateralis nucleus. Waltz, et al., reported a 13.1% incidence of immediate postoperative speech dysfunction in a series of 1001 consecutive thalamotomies for parkinsonism, but no grossly detectable dysarthria or dysphasia at a mean follow-up period of 10.6 months. Bell reported dysarthria in two-thirds of patients after right or left ventralis lateralis lesions; this complication was significantly more common following dominant hemisphere thalamotomy. Dysarthrias in the majority of Bell's patients resolved within 3 weeks, although a few patients had persistent dysarthria following dominant hemispheric lesions. Bell also noted expressive aphasia in occasional patients after dominant hemisphere thalamic lesions as well as reduced voice volume in up to one-third of patients undergoing bilateral thalamotomies.

As reported herein, using modern stereotactic techniques resulted in a substantially lower incidence of speech and language problems compared to some of the earlier experiences with stereotactic surgery. New or worsened dysarthrias were observed in seven patients in our series, but persisted in only two. Two of our patients developed transient postthalamotomy expressive aphasia and one other patient had global aphasia and delusions; all of these cleared within 1 week. Each of these patients had left ventralis lateralis lesions.

Cognitive Deficits. Cognitive deficits are also known to occur following thalamotomy. Waltz, et al., reported transient confusion and disorientation in approximately 10% of their patients, but they cleared within 1 to 7 days postoperatively. Shapiro, et al., reported more permanent albeit mild cognitive deficits in 10% to 15% of their patients. Left thalamic lesions have been associated with verbal memory and learning deficits, while right thalamic lesions have been linked to impaired visuospatial memory and nonverbal performance abilities. These deficits were usually mild and lasted from several weeks to 6 months although occasionally they persisted into the 2nd postoperative year. The literature suggests that if preoperative cognitive dysfunction is evident, or if significant atrophy is present on preoperative CT scans, the risk of significantly impaired postoperative mentation is high.

Nine of our patients were at increased risk for signif-
Stereotactic thalamotomy for parkinsonian tremor

ificant postoperative cognitive impairment based upon preoperative neuropsychological testing documenting mild or mild-to-moderate cognitive dysfunction at base-
line. Following left ventrals lateralis thalamotomy, two of these patients had transient disorientation and som-
nolence which cleared within 1 week. One other patient had postoperative abulia following left ventrals lateralis thalamotomy which persisted for several months. As noted earlier, this patient had marked cerebral atrophy demonstrated on preoperative CT scans. Finally, one patient with normal preoperative neuropsychological function has persistent mild memory and learning diff-
culties due to a probe tract hematoma.

Ventriculography. One patient in our series had a single generalized seizure following ventriculography. It is our current policy to document therapeutic anti-
convulsant serum concentrations of phenytoin or phe-
noobarbital prior to ventriculography. Anticonvulsant
agents are continued for 1 week following ventrals lateralis thalamotomy, then discontinued.

Conclusions

Although the progression of Parkinson's disease can-
not be altered by thalamotomy, disabling tremor can be abolished in 86% of cases and significantly reduced in an additional 5%. Careful patient selection, accurate preoperative documentation of neurological deficits, precise surgical localization and lesion production, as well as judicious use of postoperative antiparkinsonian medications may allow more tremor-free years for many patients with Parkinson's disease.

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