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Clinical Article

Thalamotomy without Microelectrode Recording

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Objective : Tremor, either essential tremor or Parkinsonian tremor, has been effectively and safely treated by lesioning the ventral intermediate(Vim) nucleus of the thalamus with or without mircroelectrode recording. The authors evaluate the treatment outcome of sixteen tremor patients who had been treated with thalamotomy without microelectrode.

Methods : Between September, 2001, and December, 2003, sixteen tremor patients were treated with thalamotomy without microelectrode recording. Twelve patients suffered from Parkinsonian tremor and four patients were essential tremor patients. The male to female ratio was 1.6 to 1 with median age of 59.6 years (range; 39-74 years). Under local anesthesia, a 3mm hole was made using a hand-held twist drill, and the dura mater was penetrated with a 1.2mm sharp drill beat. Radiofrequency(RF) electrode was placed in the Vim nucleus of thalamus. With intraoperative macrostimulation, RF lesion was made. Postoperative CT scan and/or MR imaging was performed to confirm the localization of the target lesioned. Preoperative and postoperative tremor was evaluated with simple tremor severity scale and the development of complications related with the procedure was closely reviewed at the immediate postoperative period and the last follow-up.

Results : It produces immediate relief in up to 98.4% of the patients. There were no development of complications related with procedure, all patients discharged one or two days after surgery.

Conclusion : Vim thalamotomy without microelectrode recording is a safe and effective procedure to control the tremor with minimal morbidity. Intraoperative macroelectrode stimulation safely localizes the Vim nucleus target of the thalamus for the treatment of patients with tremor.

KEY WORDS : Tremor · Thalamotomy · Macroelectrode.

Introduction

In the 1960s, stereotactic thalamotomy became the treatment of choice for a wide variety of movement disorders, including the tremor and rigidity of Parkinson's disease(PD)[2,19,29,33]. The ventrolateral(VL) nucleus has been recognized as the target of choice to control tremor despite the development of levodopa(L-dopa) in the late 1960 for the treatment of the bradykinesia and tremor of Parkinsonism. Tremor, either essential tremor(ET) or Parkinsonian tremor, has been effectively and safely treated by lesioning the VL (or ventral intermediate) nucleus of the thalamus with or without mircroelectrode recording. The authors evaluated the treatment outcome of sixteen tremor patients who had been treated with thalamotomy without microelectrode recording to validate the efficacy and the safety of thalamotomy with macroelectrode stimulation for the treatment of tremor. And a brief outline of the current concepts regarding the pathophysiology of parkinsonian tremor or essential tremor is presented with a review of the technique and results of thalamotomy for tremor patients.

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Materials and Methods

Patients selection and evaluation

Between September, 2001, and December, 2003, sixteen tremor patients were treated with thalamotomy without microelectrode recording. Twelve patients suffered from Parkinsonian tremor and four patients were essential tremor patients. The male to female ratio was 1.6 to 1 with the median age of 59.6 years (range; 39-74). Two patients were

Table 1. Simple tremor severity scale

	Severity
0	No tremor
1	Minimal (barely noticeable)
2	Obvious, noticeable (< 2cm)
3	Moderate, partially disabling (2cm to 4cm)
4	Severe, coarse, disabling (< 4cm)

treated in our institutes and fourteen patients were treated in Oregon Health & Science University(OHSU). Postoperative computed tomography(CT) scan and/or magnetic resonance imaging(MRI) was performed to confirm the localization of the target lesioned. Preoperative and postoperative tremor were evaluated with simple tremor severity scale[10](Table 1) and the development of complications related with the procedure was closely reviewed at the immediate postoperative period and the last follow-up.

Procedures of thalamotomy without microelectrode recording

The stereotactic frame is applied with the patient in sitting position. The local anesthetic mixture, consisting of equal amount of 0.5% bupivacaine and 1% lidocaine and epinephrine 1:200,000, is applied to the sites of screw insertion. Care is taken to align the frame in the axial plane parallel to the intercommissural line so the target coordinate calculation becomes somewhat easier. Standard Series G Leksell frame (Elekta, Atlanta, Ga., USA) may be applied and positioned with relative ease using a pair of plastic ear bars. We have found that covering the tip of each ear bar with a small piece of self-adherent plastic foam greatly reduces the patient's discomfort, to the point that sedative or analgesic medication is unnecessary. Four screws are advanced symmertically alternating between pairs of diagonally opposing screws[21]. After the frame is tightly attached to the patient' s head, the ear bars are removed, and the patient is transferred to the imaging suite.

Magnetic resonance imaging(MRI) appears to be the most appropriate imaging technique since it allows direct visualization of anatomic landmarks(the third ventricle, anterior (AC) and posterior (PC) commissures) and intracranial structures (the thalamus, internal capsule, basal ganglia) while maintaining high degree of accuracy.

Fig. 1. The Vim target in the Stealthstation.

Usually, 1mm thick contiguous T1-weighted axial MRI obtained above and below the intercommissural plane are sufficient for stereotactic planning.

Traditional coordinates for the thalamotomy target are derived from the classic stereotactic atlases, such as Schaltenbrand and Wahren[26], and these can be adjusted individually based on the intercommissural distance(IC) and size of the third ventricle. Usually, the coordinates of AC and PC are calculated first relative to the geometric center of the frame.

Most modern published series use image-based coordinates that fit into this quadrilateral space and physiologically correlate with the position of the Vim nucleus. The usual algorithms describe a point 4mm behind the midcommissural point, 13mm lateral to the midline and 1mm above the intercommissural plane[17], or 5mm anterior to PC, 15mm lateral to the midline and at the level of the intercommissural plane[22].

We used target point 4~5mm anterior to PC, 13~15mm lateal to the midline and at the level of intercommissural plane(Fig. 1).

In addition to imagebased coordinates we prefer to recalculate target position using Stealthstation(Medtronic, Mineapolis,

Table 2. Summary of the patients

Sex	male : female = 1.6 : 1
Age	median age : 59.6 years (range : 39–74 years)
Follow-up duration	median 10.5 months (range : 1–20 months)
Symptom duration	median 5.1 years (range : 3–10 years)
Lesion localization	right : left = 6 : 10

Outcome	Preoperation		Postoperation	
	Tremor scale	No. of cases	Tremor scale	No. of cases
Parkinsonism (n=12)	4	9	0	8
	3	3	0	3
Essential Tremor (n=4)	3	4	0	4

MN)(Fig. 1) or Gammaplan(Elekta Instruments, Atlanta, Ga). However, because of the intersubject variability of anatomy, target determination based on the imaging alone is insufficient. The final position of the thalamotomy target is adjusted based on results of the intraoperative stimulation.

Once the target coordinates are selected, the patient is taken to the operating room where he or she is placed on the operating table and the head frame is attached to a standard Mayfield headholder via an adapter. Appropriate padding and warm blankets are used to keep the patient comfortable throughout the procedure. Monitoring is used primarily for blood pressure control and suppression of intraoperative hypertension.

The stereotactic arc of Leksell system is attached to the frame and its angle is adjusted to a trajectory about 5° lateral to the sagittal plane and 60~70° anteriorly relative to the intercommissural axial plane. The skin and periosteum infiltrated with local anesthetic. A 3mm hole is made using a hand-held twist drill, and the dura mater is penetrated with a 1.2mm sharp drill bit. After that, a cannula is inserted into the brain matter along the stereotactic trajectory and its tip is positioned 12mm above the target point.

A standard radiofrequency electrode with a 1.6~1.8mm diameter and a 2~3mm bare tip is placed in the desired position throughout the cannula. Patients' tremor was closely monitored immediately prior to and during the electrode insertion because in some cases the tremor may disappear or significantly decreased from the so-called 'microthalamotomy' effect which is related to a local mechanical injury of the ventral intermediate nucleus by the inserted electrode[2].

Stimulation was performed at three different frequencies with gradually increasing electrical current. First, 2Hz stimulation is performed with careful observation of evoked motor activity. The operator holds the patient's contralateral arm while also observing facial movements. A current of 1~2 V usually elicits muscle contraction in the contralateral arm. Lower stimulation threshold indicates proximity of the electrode tip to the pyramidal tract in the posterior limb of the internal capsule and requires more medial placement of the target. Second stimulation trial is aimed at sensory response. It is performed at 50Hz frequency with 1ms pulse width, and the patient is asked to report induced sensations (paresthesias), usually described as mild tingling. Adequate position of the electrode is associated with paresthesias in the contralateral corner of the mouth (labial commissure) and the thumb and index finger at about 1.5 V. Lower sensory threshold (< 1.0 V) indicates position of the electrode tip inside the ventral caudalis nucleus, whereas much higher thresholds suggest that the electrode is positioned too far anteriorly. Development of paresthesias in the leg and lower body may be a sign of the lateral electrode placement, which may by more appropriate for patients with predominance of the lower extremity tremor.

A goal of the third stimulation trial that is done at 180~200 Hz frequency is to suppress the tremor. In cases of appropriate electrode placement, this stimulation may suppress tremor completely at current intensity at or below 0.5 V.

The initial test lesion is usually made at 45° for 10 seconds. If the patient tolerates this lesion without new deficits, the probe temperature is raised to 70~72° and maintained at this level for 60 seconds while the patient is continuously tested for speech and the hand strength. Once the lesion at the target point is completed, the electrode is withdrawn 2mm and the second lesion is made, and then withdrawn an additional 2 mm (4mm from the target point) for the third lesion along the same trajectory(Fig. 2).

Results

There was no development of complications after thalamotomy without microelectrode recording. Immediate relief of tremor after procedure was observed in all but one patient (96% tremor control rate). All patients discharged one or two days after surgery. The median follow-up period was 10.5months(range; 1~20months). Male to female ratio was 1.6:1. The median age was 59.6 years(range; 39~74 years). Median symptom duration was 5.1 years(range; 3~10 years). Lesion localization was right; 6, left; 10. Tremor scale was improved in 7 patients from grade 3 to grade 0, 8 patients from grade 4 to grade 0, 1 patient from grade 4 to grade 1, at the last follow-up period after thalamotomy. Tremor scale was improved from 3 to 0 in four essential tremor patients. Among twelve Parkinsonian tremor patients, tremor scale was improved in eight patients from grade 4 to grade 0, three patients from grade 3 to grade 0, and one patient from grade 4 to grade 1 (Table 2). All the lesioned target points demonstrated in CT scan or MR images was correctly localized at the same site planned before thalamotomy.

Discussion

Stereotactic Vim thalamotomy is indicated for drug-refractory tremor of various etiologies. The two most common pathological conditions that are treated with thalamotomy are PD and essential tremor ET[16,32]. Tremor of

Table 3. Literature reviews of the thalamotomy

Author	No. of cases	Tremor control (%)	Follow-up period (Months)	Complications (%)
Fox, et al[11]	36	86%	3-12	5 patients(13.9%)
Goldmon, et al[13,14]	14	81.8%	23.4	3 patients(21.4%)
Jankovic, et al[18]	60	86% : Parkinsonism 83% : essential tremor	52.0	transient : 58%
Shahzadi, et al[27]	93	86%	3-12	83.9%
Tasker, et al[31]	38	62.5% : DBS* 63.7% : thalamotomy	9.2	34.5% : transient (DBS*) 34.2% : transient (thalamotomy) 34.2% : permanent
Wester, et al[34]	51	80%	24	18 patients(35.3%)
Giller, et al[12]	35	88%	12	6 patiehts(17.1%)
Cho, et al[7]	156	99%	12	33%
Brophy, et al[4]	25	60%	24	3 patients(12%)
Hariz, et al[15]	61	86.8%	11	7 patients(11.5%)
Taira, et al[30]	22	100%	6	30%

* DBS : Deep Brain Stimulation

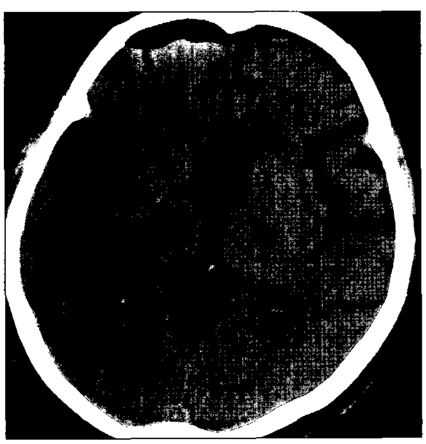

Fig. 2. Postoperative computed tomography shows the left thalamic lesion.

cerebellar and posttraumatic origin and other movement disorders, such as chorea, athetosis, hemiballism of dystonia, comprise another group of diseases that may be successfully treated with Vim thalamotomy, although the results for these latter conditions are much less favorable than PD or ET. Special considerations are used for selection of patients for second-side thalamotomy in bilateral disease. First of all, the initial operation is usually performed on the more symptomatic side or on the dominant side in cases of equal severity of symptoms. If the first operation is successful and results in complete disappearance of the tremor, the second operation may be deferred because of the high incidence of postoperative complications, particularly hypophonia and other speech disorders. Generally, in these cases we prefer unilateral thalamotomy with contralateral thalamic stimulation to bilateral thalamotomy[28]. If a patient presents with bilateral severe tremor and prefers to proceed with one-time bilateral intervention, then bilateral thalamic stimulation may be the reasonable choice of treatment[3].

Thalamotomy is a highly effective procedure for control of parkinsonian and nonparkinsonian tremor. It produces immediate relief in up to 95~100% of patients[28]. Although effectiveness of the procedure decreases over time, most series in the literature report more than 50% overall long-term effect of stereotactic thalamotomy on tremor suppression[25]. It appears that patients with essential tremor and stable PD maintain higher rate of surgical success on long-term follow-up comparing to patients with progressive parkinsonism who lose their functional status because of the ongoing neurological deterioration. It has also been noted that the majority of recurrences take place within first 3 months after surgery[11].

Intraoperative stimulation results require repositioning of the electrode in approximately one-half of the patients[18]. This is similar to results reported by groups using microelectrode recording for physiological confirmation of the target position[16].

Destruction of the ventral intermediate nucleus at the target point is performed using RF heating of the tissue. Although other technuqies of local tissue ablation were used in the past, RF thermocoagulation is currently accepted as most reliable, reproducible and predictable means of focal tissue lesion production[1]. It must be mentioned, however, that large historical series of thalamotomies utilized chemical destruction with local instillation of absolute alcohol (chemothalamotomy)[8] and cryoablation (freezing) of the target area with a special cannula refrigerated by liquid nitrogen (cryothalamotomy)[28,33].

The RF lesion is performed at the final target point with continuous testing of the patient' s speech and motor strength. Usually, a series of test lesions are performed first so the procedure may be aborted and target position adjusted before the development of irreversible damage.

These coagulation parameters result in ovoid shape lesion with volume of 40~60mm^3. Such lesion is usually sufficient for tremor control in patients with parkinsonism and essential tremor. For posttraumatic and poststroke tremor, a target lesion measuring 100~200mm^3 may be required. Largest lesions may be achieved by larger electrode tip diameter, higher electrode tip temperature and a longer coagulation period (90~120 seconds).

If the tremor persists after the RF lesion is completed, and the patient tolerated procedure without development of new symptoms, it is recommended to either enlarge lesion in its original position by additional RF heating to a higher temperature or to move the electrode to another target point, usually 1~2mm posterior and/or ventral to the initial lesion[18]. Macrostimulation mapping should be repeated at each new position of the electrode in order to prevent development of undesired effects and complications.

The thalamotomy target for tremor control is located in the mid-portion of the ventral thalamus, corresponding to the Vim in the Hassler nomenclature and posterolateral VL of Anglo-American nomenclature[5]. This nucleus is located in the middle of the ventrolateral thalamic mass rostral to the ventrocaudal nucleus (VC) and caudal to the ventro-oral nucleus. Laterally, it is adjacent to the posterior limb of the internal capsule, and medially it is bordering the centrum medianum(CM) of the thalamus. The nucleus measures 10 mm in lateral and superioinferior dimensions and 3~4mm in anteroposterior dimension, and is inclined 20° anteriorly.

The Vim receives kinesthetic afferent input from the contralateral body parts and may by concerned with muscle sensation. It contains large neurons that sometimes discharge synchronously with peripheral tremor ('tremor cells'). Many of these cells are simply somatosensory neurons that respond to joint movements, but the majority of tremor cells have peak discharges preceding the electromyographic signal. That may indicate that tremor cells are involved in tremor production rather than sensory feedback from tremulous body part[9,17,20], and might be thought of as tremor 'pacemaker' cells. Detailed studies of physiological activity of Vim neurons have shown presence of somatotopic organization within the nucleus. The contralateral leg area is represented in the dorsolateral part of the nucleus, the face in the most medial part, and the arm area between them and somewhat ventrally[24]. The VC nucleus of the thalamus is also somatotopically organized, with the sensory homunculus that has its face located medially and leg laterally[18]. A constant relationship between somatotopically arranged cells in Vim and VC nuclei allows us to pinpoint targets for tremor-relieving procedures by sensory stimulation of adjacent VC neurons[5].

Analysis of the current literature shows that results of stereotactic thalamotomy are quite consistent, and independent of the technique of intraoperative target localization. We performed meta-analysis of 13 large clinical series that were published. Since there is an issue of possible added benefit of intraoperative microrecording and microstimulation, we compared results of reported series that routinely use microelectrodes during stereotactic thalamotomies[11,13,14,18,27,31] with those that confirm imaging-derived coordinates by intraoperative physiological testing using macrostimulation[4,7,12,15,30,34].

Fox, et al[11] underwent thalamotomy with microelectrode recording for 36 medically refractory tremor in post-levodopa era Parkinson's disease patients, 86% had complete abolition of tremor and 5% had significant improvement. Persistent complications (arm dyspraxia, dysarthria, dysphasia, or abulia) were noted in five patients(Table 3).

Goldman, et al[13,14] operated with thalamotomy with microelectrode recording in 14 intention tremor patients, 2 patients developed mild, nondisabling dysarthrias, one elderly patient died of pulmonary complications. Jankovic, et al[18] analyzed the outcomes of 60 patients with medically intractable tremor who underwent stereotactic thalamotomy with microelectrode recording. Of these 60 patients, 42 had Parkinson' s disease, 6 had essential tremor, 6 had cerebellar tremor, and 6 had post-traumatic tremor. 86% of the patients with Parkinson' s disease, 83% of the patients with essential tremor, 67% of the patients with cerebellar tremor, and 50% of the patients with post-traumatic tremor had cessation of or moderate-to-marked improvement in their contralateral tremor. Immediate postoperative complications were occuring in 58% of patients. The most common complications were contralateral weakness(34%), dysarthria(29%), and confusion(23%). Shahzadi, et al[27] reported thalamotomy result with microelectrode recording in 22 essential tremor, 46 multiple sclerosis with tremor, 9 undiagnosed tremor, 11 posttraumatic tremor, 5 post stroke tremor. In 86% of the essential tremor patients suppressed the tremor. In multiple sclerosis patients, 67% showed significant suppression of tremor(Table 3).

In other tremors, 52% relieved the tremor. But, complications were developed in 78 patients (83.9%). Complications consisted of 14 transient dysarthria, 10 transient hemiparesis, 10 persistent hemiparesis, 8 persistent numbness, 5 transient numbness, 6 transient cognitive disturbance, 4 persistent dysarthria, 4 seizures, etc. Tasker, et al[31] underwent 20 Deep Brain Stimulation operations and 35 thalamotomy operations. Tremor was abolished 62.5% in the Deep Brain Stimulation operation group, 63.7% in the thalamotomy group. Slight improved in 31.3% of the Deep Brain Stimulation operation group, 13.6% of the thal-amotomy group. In Deep Brain Stimulation operation groups, complications were following; 10% of transient hand ataxia, 5%

of transient gait disturbance, 5% of permanent gait disturbance, 5% of hemiparesis, 4.5% of the transient paresthesias, 10% of the transient other complications.

In thalamotomy groups, complications were following; 11.4% of the permanent paresthesia, 5.7% of the transient paresthesia, 14.2% of the permanent hand ataxia, 2.9% of the transient hand ataxia, 5.7% of the transient dysarthria, 2.9% of the permanent dysarthria, 5.7% of the parkinsonian crisis, 5.8% of the other transient complications.

Wester, et al[34], underwent 51 thalamotomy operations without microelectrode recording, 80% of these patients gained a substantial benefit in their daily lives, 18 patients(35.3%) developed the complications; hemiparesis ; 6, dysphasia ; 5, dysarthria ; 1, etc. Giller, et al[12] performed 35 thalamotomies without microelectrode recording, 65% experienced near-complete or complete tremor resolution, 23% experienced partial tremor relief. Six patients(17.1%) sustained temporary neurological deficits such as hemiparesis or dysarthria. One patient sustained a superficial infection, and one patient experienced worsening of balance(Table 3). Cho, et al[7] performed 138 thalamotomies without micro-electrode recording, 99% led to improvement of tremor. Howerver, complications included hypotonia(24%), transient confusion(19%), transient dysphasia(11%), permanent dysarthria(7%), subjective numbness(4%) and epileptic seizure(3%). Brophy, et al[4] underwent 25 thalamotomy operations without microelectrode recording, good outcome was achieved in 66% of the cases, three patients sustained a significant new deficit(cutaneous sensory loss, hemiparesis)(Table 3). Hariz, et al[15] underwent 61 thalamotomy operations without microelectrode recording, 86.8% of the patients showed excellent or fair result. 7 patients(11.5%) showed dysphasia, dysarthria, disturbance of balence, confusion, numbness. Taira, et al[30] reported operative results in 22 patients who underwent stereotactic thalamotomy for tremor control, tremors were completely arrested immediately after the operation in 100% patients with Parkinson's disease, 83% patients with multiple sclerosis. Transient and permanent complications were seen in 7(30%) patients(Table 3).

In our study, initial success rate was 98.4%. The long-term success rate at 10.5months's follow-up was 98.4%. There were no complications.

Although we strongly support use of microrecording in operations on the globus pallidus and the subthalamic nucleus, we think that stereotactic thalamotomy may be safely performed without use of the microelectrodes. The reason for this is that thalamotomy target in the ventrobasal thalamus is relatively 'forgiving'. First of all, there is a range of locations in this region in which a lesion produced by thalamotomy will result in good outcome[13]. Second, the morbidity of the procedure may be minimal as long as the neurosurgeon avoids damage to the pyramidal tract from too lateral placement of the lesion. Finally, the end point for the procedure is fairly 'hard', in that arrest of tremor by test stimulation or test lesions can be readily observed[6].

Conclusion

Vim thalamotomy without microelectrode recording was a safe and effective procedure to control the tremor compared with the results of the thalamotomy with microelectrode recording in the literature review. Intraoperative macroelectrode stimulation safely localized the Vim nucleus target of the thalamus for the treatment of patients with tremor.

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