Delineation of the thalamic nuclei with a microelectrode in stereotaxic surgery for parkinsonism and cerebral palsy

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Extracellular thalamic recording with semi-microelectrode during 103 cases of stereotaxic surgery identified the upper and lower borders of the thalamus and the anterior limit of the sensory area. In adults the upper border of the thalamus was found 13 to 21 mm above the intercommissural line and the lower border within 1 mm above and below the intercommissural line. In children under 10 years with cerebral palsy, the upper border was comparable to that in adults while the lower border was about 1 mm below the intercommissural line. In adults the inferior border determined by the thalamocortical evoked potential was always about 2 to 3 mm above the intercommissural line. The anterior limit of the sensory nucleus, which seemed to be specifically related to the neurons activated by muscle compression and active or passive joint movement, was 3 to 4 mm behind the perpendicular line at the midpoint of the intercommissural line. The target point was determined by using these physiological findings combined with radiological control. This method has produced improved operative results in the treatment of parkinsonism.

KEY WORDS: stereotaxic surgery · microelectrode recording · evoked thalamocortical potential · thalamus · continuous depth recording

Although L-dopa therapy is the first choice in the treatment for certain manifestations of parkinsonism, stereotaxic operations on the thalamus or subthalamus are still useful for such extrapyramidal manifestations as tremor, rigidity, and athetosis.14,15

Exact location of the target is usually based on radiological measurement related to the third ventricle, especially the anterior and posterior commissures and the midline. Physiological techniques are also applied for more precise localization of the electrode tip within the thalamus; for example, the observation of the motor effects of high-frequency stimulation and the recording of the rhythmic cortical potentials evoked by low-frequency thalamic stimulation have been proved to be quite important.16,18,22,24

Since about 1960, the Paris group1,2,7–10,21 has developed a microelectrode technique by which each different thalamic nucleus
Delineation of the human thalamus

and the internal capsule can be identified precisely. Through a semimicroelectrode inserted from a posterior-to-anterior direction almost parallel to the intercommissural line (IC line), they recorded the multiunitary discharges of each nucleus and also the evoked activity in the ventroposterior nucleus (VP) corresponding to the natural peripheral stimuli. They stated that this procedure greatly reduced the risk during thalamic surgery. At about the same time, using a tungsten microelectrode in an anterior-to-posterior coronal approach, the Montreal group recorded unitary cellular activities in the human thalamus, particularly in the sensory area, and claimed that the anterior limit of the tactile area of the VP can be well identified.

We utilized unitary thalamic recording in addition to other electrophysiological devices to improve precision in locating the target. In this paper we are describing a quantitative study of the upper and lower borders of the thalamus and the anterior limit of the sensory area thus determined and the effects of operations by those methods, especially the depth recording.

Materials and Methods

The present report is based upon observations of depth recordings in 94 patients operated on since December, 1969; 45 had parkinsonism, 35 cerebral palsy, 12 others involuntary movements, one phantom pain, and one thalamic pain. Observations were also made on the thalamocortical evoked responses recorded in nine parkinsonian patients in 1966. All patients with parkinsonism or with pain, two with cerebral palsy, and nine with involuntary movements were operated on under local anesthesia with slight premedication (10 mg of chlorpromazine). Thirty-six other cases, mostly children with cerebral palsy and a small number of patients with other involuntary movements, were operated on under general anesthesia by intravenous pentobarbital administration (10 mg/kg) or by halothane.

The steel recording electrode was a bipolar concentric type with an outer diameter of 0.8 mm and an inner diameter of 0.5 mm, coated by Insl-X, except its tip, which was mechanically polished and sharpened by a diamond grinder* to about 10 to 20 μ with a resistance around 100 to 500 kilohms (kΩ). Usually the neural activity was recorded monopolarly from the tip of the semi-microelectrode. The second pole, 0.5 to 1.0 mm from the tip, was mostly used for the simultaneous recording of a local depth electroencephalogram (EEG). If necessary, bipolar recording or local stimulation was made between these two poles. In this manner, unitary or multiunitary extracellular activities could be recorded without the aid of a cathode follower. Moreover, recording or stimulation could be selected any time by use of a switch box.

In the case of depth recording, suitably amplified with a high-gain amplifier,† the neural activity was displayed on a cathode ray oscilloscope and photographed on a running film. At the same time, it was also recorded on magnetic tape with the aid of a data recorder* for future analysis. Furthermore, to facilitate the procedure, the spikes were monitored on a loud speaker.

The electrode was covered by a slightly larger guide needle, 1.0 mm in diameter, and inserted through a small burr hole in the frontoparietal area, located about 25 to 30 mm lateral to the midline and about 30 mm frontal to the perpendicular plane through the auditory meatus; thus, direction of the needle toward the thalamus was anterolateral to posteromedial. The electrode insertion was controlled by a three-stage manipulator,§ the first rough manipulator graduated in millimeters, the second in 100 μ, and the final hydraulic manipulator in micron steps.

During insertion of the electrode, location of the tip was repeatedly checked under radiological control referring to the third ventricle after PVG. For the sake of convenience, if the intercommissural (IC)
distance was 24 mm, a point 4 to 5 mm behind the midpoint of the IC-line, and just on this line in the lateral view, and 14 to 15 mm lateral from the midline in the anteroposterior view on x-ray film, was chosen as a tentative target of the so-called sub-Vim area and a spot 2 to 3 mm anterior to this point as a target of the so-called sub-VL area.

Together with micro-recording and deep EEG, the frontal, parietal, precentral, post-central, and occipital scalp EEG's and the corticogram under a burr hole for needle insertion were recorded on a 13-channel pen-writing oscillograph, an indifferent electrode being on the nose. A surface bipolar electromyogram (EMG) of the contralateral extremity was also recorded on the cathode ray oscilloscope or pen-writing oscillograph, if necessary. When sensory neurons were detected, touch, pressure, or joint movement were signalled with a small strain gauge attached to the appropriate area.

On the other hand, the potentials of the scalp EEG or corticograms evoked by thalamic stimulation were displayed on the cathode ray oscilloscope or averaged with a small computer* for easier demonstration. The stimulus for evoking responses was a square pulse of 0.5 msec, 6/sec, and around 20 V.

When the optimum target had been determined radiologically and electrophysiologically, a lesion was made by electrical coagulation with about 80°C and 30 to 60 sec in duration.

Results

Upper and Lower Limits of the Thalamus

A typical case was that of a 21-year-old woman with violent postural tremor in the right arm (Fig. 1). The right column of Fig. 1 shows examples of the cellular activities recorded during the course of insertion of the electrode to the thalamus; the left column shows averaged cortical responses evoked by low-frequency deep-brain stimulation (6/sec, 20 V) during withdrawing the needle. In this case, recording and stimulation were done at almost the same points along a needle track penetrating the spot 6 mm behind the midpoint of the IC-line and 13 mm lateral from the midline, as shown in the upper part of the figure.

In the white matter, or at a point +44 mm above the IC-line, the oscilloscope trace and the loud speaker sound indicated a constant low-background noise, and stimulation revealed the so-called direct response of a negative wave of short latency. At a point +24, irregular continuous spike discharges with slightly long duration and a large gradual positive-negative sequence with long latency in the cortical evoked discharge were so characteristic that it seemed certain that the tip was in the caudate nucleus. At a point +22, the oscilloscope trace became silent, suggesting that the tip of the needle had now entered the white matter ventral to the caudate. When the tip of the electrode arrived at a point +20, the background activity increased, and the small spikes with crackling noise started on the loud speaker. The evoked response was a high amplitude negative potential of about 400 µV, its peak latency being 50 to 60 msec, which was characteristic of the dorsal part of the thalamus. As the electrode was slowly inserted, various burst discharges were recorded at points between +17 and +2, while rhythmic cortical potentials with four and five phases, characteristic of VL, were produced by the thalamic stimulations, for example at points +8 and +5. Passing through point +2 where the stimulation evoked no definite responses on the cortex, the cellular activities still existed. At a point −0.4, the latter disappeared almost completely. This point was, therefore, considered to be the lower limit of the thalamus determined by the depth recording; it was about 2 mm below the point at which the evoked cortical response had disappeared. In this tracking, sensory neurons responding to peripheral natural stimuli could not be detected.

This case demonstrated that the depth recording gives us continuous information regarding the descent of the electrode into subcortical structures, and therefore is reliable for identifying and delineating the

*Small computer manufactured by Nohonkoh-den Medical Electronic Apparatus Co., Ltd., 1-31-4, Nishi-ochiai, Shinjuku, Tokyo, Japan.
Delineation of the human thalamus

Fig. 1. Simultaneous demonstration of recordings in the depth of the brain (right column) and averaged cortical evoked potentials by low-frequency thalamic stimulations (left column) in a 21-year-old woman who showed right hemiparesis and postural tremor in the right arm after a vascular accident. Numbers indicate the distance in millimeters from the IC line. Upper figures show the direction of the track projected to the shadow of the third ventricle in its lateral (left) and anteroposterior (right) views after PVG. The intercommissural distance was 26 mm and the maximum width of the third ventricle was 10 mm as measured by x-ray.

thalamic point. In this method, the upper border of the thalamus is detected by a sudden increase of spontaneous cellular discharges as well as a crackling noise on the loud speaker; moreover, the inferior margin of the thalamus, whose delineation is so important for the accurate destruction of the so-called sub-Vim and/or sub-VL area,
Akira Fukamachi, Chihiro Ohye and Hirotaro Narabayashi

FIG. 2. Upper and inferior borders of the thalamus identified by operative depth recording in 66 adult cases (upper) are shown with reproductions from Schaltenbrand and Bailey's atlases (lower). Open circles represent the upper limits (47 cases) and filled circles the inferior ones (38 cases). Note that the anteroposterior view of the atlas at F.p. 5.0 is selected for referring the inferior border, and therefore the upper limit in this view is actually more anterior, and so cannot be compared with the atlas. Vim = nucleus ventralis intermedius, Voa = nucleus ventrooralis anterior, Vop = nucleus ventrooralis posterior, Zi = zona incerta, Sth = nucleus subthalamicus, Ru = nucleus ruber tegmenti. Ce = nucleus centrum medianum.

...is defined fairly clearly by the reduction or disappearance of cellular activities.

Figure 2 shows the upper and lower limits determined by Schaltenbrand and Bailey's Atlases for 66 adult patients over 18 years of age, most of whom were operated on under local anesthesia. The upper thalamic limit could be plotted in 47 cases and the lower in 38. A considerable dispersion located between 13 and 20 mm above the IC line was noted in regard to the upper limits. However, the inferior margins of the thalamus corresponded well with those in the Atlas; most were within 1 mm above and below the IC line in 68.4% of the cases. In six cases, however, the limits determined by the depth recordings were located between 3 and 5 mm below the IC line. In this series, the inferior limit was identified less often than the upper one, perhaps due to some technical reasons. For example, in cases in which sensory neurons were detected, the needles were not introduced further and the inferior borders remained unconfirmed. Figure 3 records 10 recent adult cases in which both the upper and lower limits of the thalamus were precisely identified by this method during operation. In this group the
Delineation of the human thalamus

**Fig. 3.** Record of 10 recent adult cases in which both the upper and lower limits of the thalamus were determined by depth recording and projected to the shadow of the third ventricle. ML = midline. Open circles represent the upper thalamic limit and filled circles the inferior limit. Circles joined by a short line indicate an individual case. Lines in the anteroposterior view (right) do not represent the actual length, because these circles are simply transferred from the lateral view in accordance with their distance from the midline. AC = anterior commissure, PC = posterior commissure, MP = midpoint, numbers in millimeters.

Distance between the upper and lower limits ranged from 15.8 to 20.0 mm, the average being 18.1 mm.

Figure 4 shows the upper and lower margins of the thalamus determined in the same manner in 21 children less than 10 years old under general anesthesia. In this group, as in adult cases, there was a dispersion of the upper border measurements, while the inferior margins concentrated around 1 mm below the IC line; the average distance between the upper and lower limits was 18.2 mm. Although the upper border seemed to be slightly lower than that in adult cases, exact comparison was not possible from this small number of cases.

**Inferior Border of the Thalamus Determined by Thalamocortical Evoked Potentials**

In nine parkinsonian patients, low-frequency stimulation of the VL nucleus and its dorsal and ventral areas was carried out with a consistent intensity of 20 V, 6/sec. Figure 5 shows the changes in amplitude of the evoked responses on scalp EEG's (three cases) and corticograms (six cases). In every case, two peaks were found in our usual tracking, one at the level of the dorsal nucleus and the other at the VL nucleus. The points at which stimulation produced abrupt reductions of amplitudes in evoked responses were always 2 to 3 mm above the IC line; these points had been considered to be the inferior limits of the thalamus determined by this method. Also in the case described in Fig. 1, the inferior margin defined by the reduction of cellular activities was 2 to 3 mm lower than that determined by the evoked potential method.

**Anterior Limit of the Thalamic Sensory Area**

In 20 cases, 42 neurons in and around the VP nucleus were found responsive to certain kinds of natural contralateral peripheral stimuli such as light touch, pressure, muscle stretch, or movement of a joint. The peripheral receptive fields and modalities of
sensation and their trackings are shown in Fig. 6. Usually the so-called tactile zone in the ventroposterior nucleus, destruction of which would cause troublesome sensory disturbances, could be identified by an intense background activity and abundant spike firings on the oscilloscope trace as well as by the increase of noise on the loud

**Fig. 4.** In 21 children under 10 years old, the upper or inferior limit was identified by depth recording and projected as in Fig. 3. Upper limits (open circles) were identified in 13 cases and inferior ones (filled circles) in 19. Straight short lines combining both the upper and inferior borders denote individual cases. MP = midpoint of the IC line, AC = anterior commissure, PC = posterior commissure, ML = midline.

**Fig. 5.** Low-frequency thalamic stimulations performed in nine patients with parkinsonism; evoked potential changes in maximum amplitude in six cortical readings (o—o) and three scalp recordings (x—x). The abscissa represents maximum amplitude (peak to peak, μV) and ordinate the distance of the electrode tip from the IC line.
Delineation of the human thalamus

Fig. 6. Relation of peripheral stimulation to thalamic neuron. Forty-two sensory neurons (20 cases) are shown together with their peripheral receptor fields, modalities of sensation, and tracking in the posterior part of the thalamus (lateral view); MP = the midpoint of the IC line. Small filled circles in figurines represent cells responding to light touch or pressure. Arrows, "jaw open" and "jaw closed," and small dots represent cells related to kinesthesia such as muscle stretch, muscle compression, and joint movement. Schematic figure of the front view of the upper half of the body near the posterior commissure (CP) indicated a patient with post-amputation phantom pain in which a sensory neuron with a wide receptor field was recorded near the nucleus centrum medianum.

speaker in response to light touch or pressure applied to small peripheral receptor fields on the contralateral side. These thalamic tactile neurons were located around the posterior commissure (PC), and most of them were within a radius of 5 mm from the PC on the lateral view; one, however, was found in a fairly anterior area, namely, along a track crossing over a point 5 mm behind the midpoint on the IC line.

On the other hand, cells responding to muscle compression, muscle stretch, and active or passive joint movement (kinesthesia) were found more anteriorly than the tactile zone. The anterior border of this area was 3 to 4 mm behind the perpendicular line at the midpoint of the IC line, the upper border about 7 to 10 mm above the line, and the inferior border 2 to 3 mm below the line. This area was between 13 and 18 mm lateral to the midline. Consequently, when tracking passes through this area, namely, as in a tracking passing over a point on the IC line more than 4 to 5 mm behind the midpoint in the lateral view, muscle compression, muscle stretch, and joint move-
Effects of Operations

The results of recent operations for parkinsonism were excellent. The EMG examination 2 to 3 weeks after operation in 48 patients operated on from January, 1970, to May, 1971, showed that rigidity had been abolished in 98% of the cases and tremor in 86.7%. These values were slightly higher than previous results (Fig. 7).

Side effects of the thalamic stereotaxic operations in the 84 cases operated on from December, 1969, to October, 1971, included: two cases with sensory disturbance in a small localized area; one patient who developed a slightly different type of tremor in the proximal muscles in spite of the disappearance of the peripheral tremor; and two patients who showed a slight transient hemiparesis and disturbance of consciousness. In one case, numbness was found immediately after operation in the skin receptor area stimulated, and might have been due to destruction of the recording point in the tactile zone of the ventroposterior nucleus by the electrode itself. In another case, hypesthesia and dysesthesia were found in the left labial angle and the left side of the tongue after a relatively large lesion had been made at a point 2 to 3 mm below the recording point where a neuron responding to passive flexion of a distal joint of the left thumb had been detected. In the two cases with transient hemiparesis, it was considered that the lesions had extended to the internal capsule. The problem of transfer of the tremor from the peripheral muscles to proximal ones in one case needs further investigation.

Discussion

The importance of the electrophysiological devices to safeguard thalamic stereotaxic operations has been discussed by many investigators. Guiot, et al.,8,21 warned that paresthesia, ballismus, mental change, spasticity, and dysarthria might be expected if the lesion was placed improperly. Operations that rely only on radiological measurements might introduce avoidable hazards. In fact, Taren, et al.,21 stressed the fact that to ignore neurophysiological corroboration adds a risk of 30 to 40% morbidity, which is unacceptably high for a noncurative procedure.
Delineation of the human thalamus

To overcome these difficulties and to increase the effectiveness of operations, the use of electrophysiological methods such as thalamocortical evoked potential and depth recording to supplement radiological control is important. The fact that only 6% of our 84 patients operated on with the aid of electrophysiological methods developed harmful side effects emphasizes the importance of these additional methods. Moreover, in only one case was the side effect produced by the recording or stimulating electrode itself, and therefore these examinations themselves proved almost harmless.

The thalamocortical evoked potential method clearly identifies the VL nucleus. On the other hand, continuous depth recording with a microelectrode identifies the upper and lower borders of the thalamus and the thalamic sensory area more easily. The effectiveness of recent operations incorporating the aid of these methods was slightly better than that of previous operations. Although other contemporary changes such as L-dopa therapy, selection of the target point, etc., are also factors, the use of depth recording and the evoked potential method both improved the results of surgery. Final evaluation should await the results of the long-term follow-up which is now going on.

Our studies in adult cases showed considerable variation in the upper limit of the thalamus. This is attributed to individual variations as well as technical problems. The direction taken by the electrode to the thalamus was always very different, even though the tentative targets were almost the same; in fact, the angles between the electrode and IC line on the lateral view of the x-ray film varied from 48° to 78°. Moreover, manipulations of the electrodes were imprecise in the upper area because this area was not concerned with the final target. On the other hand, the problem of manipulation was negligible in the inferior area because of the use of a micromanipulator to determine precisely the area to be destroyed. In 70% of the cases in which the inferior limit had been determined by the depth recording it concentrated on an area within 1 mm above or below the IC line; these variations were comparable to those reported by Hardy,11 and Van Buren and Maccubbin.20 In six cases, however, the point of decrease or disappearance of the cellular activity was in an area 3 to 5 mm below the IC line; in such cases, it would be better to determine the inferior limit with the additional aid of thalamocortical evoked potentials. It is noteworthy that there was a difference of 2 to 3 mm between these two methods to determine the inferior limit of the thalamus. Although the reason for this difference is not clear, one possibility is that the density of the projecting fibers from the VL nucleus to the cerebral cortex is less in the lower part of the VL by comparison with that in the dorsal part. Subthalamotomy after well-defined localization of the inferior border never produced postoperative hemiballismus. Although there were relatively few cases of children under 10 years old, the determinations of the upper and lower limits of the thalamus were almost the same as those in adults.

The tactile zone in the thalamic sensory area was found at the end of the needle track in our anterior-to-posterior approach. As reported by Bertrand, et al.,4,5 the anterior limit of the zone seemed to vary considerably, but the neurons responding to light touch or pressure were distributed around the PC and most of them were within a circle with a radius of 5 mm from the PC in the lateral view. In front of this area, we found the cells related to kinesthesia forming a region which corresponds well to the Vim, in which potentials were evoked by excitation of low threshold muscle afferents.6 Bertrand, et al.,4,5 claimed that the most effective thalamic lesions against parkinsonism tremor are made in the deep sensory relay area in front of the cutaneous tactile zone. In one of our patients the lesion was made in the area immediately ventral to a recording point where passive flexion of the left thumb had induced neuronal discharge; however, although this abolished the tremor it also resulted in hypesthesia and dysesthesia of the left labial angle and the left half of the tongue. We therefore feel that although the destruction of the deep sensory relay area might be the optimal target for arrest of tremor, any lesion in this area must be carefully restricted.

The somatotopic arrangement of tactile representation on the VP nucleus was very
suggestive of that reported by Albe-Fessard, et al., but our material was insufficient to confirm this arrangement.

A detailed description of the thalamic sensory area is given elsewhere.

Summary

We have reported our recent experiences with electrophysiological methods, particularly of thalamic recording with microelectrodes, during stereotaxic surgery. The following results were obtained and discussed from the practical point of view. The thalamic recording provided continuous information in the depth of brain, along a track toward the target point, and is very reliable for identifying and delineating the recording point. The upper limit of the thalamus, detected by sudden increase of cellular discharges, was between 13 and 21 mm above the intercommissural line in our anteroposterior approach in 66 adult cases over 18 years of age and not essentially different in children under 10 years. The inferior margin of the thalamus, which is an important landmark for coagulation of sub-VL and/or sub-Vim areas, was identified by the reduction or disappearance of cellular discharges. In most of the patients over 18 years, it was within 1 mm above and below the IC line. On the other hand, in most of the patients under 10 years of age, it is usually 1 mm below the line. The inferior limit determined by a thalamocortical evoked potential was 2 to 3 mm above the IC line; this created a 2 to 3 mm difference when compared to the inferior limit estimated by the microelectrode technique. The upper or anterior limit of the thalamic sensory area was detected by the increased spontaneous background activity and the responses to peripheral stimulations of various modalities. The sensory area thus determined was 3 to 4 mm behind the midpoint of the IC line anteriorly and about 7 mm above the IC line superiorly. With the aid of these techniques, the effectiveness of operations for parkinsonism was improved and the postoperative side effects were minimal.

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Delineation of the human thalamus


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