Electrical Exploration of the Internal Capsule and Neighbouring Structures During Stereotaxic Procedures*

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The variability in position, shape and size of deep cerebral structures in relation to radiologically visible landmarks hardly needs to be stressed again and even the most careful plotting of a target point and the most precise instrumentation leave a margin of error which becomes more important as the target is situated farther away from the landmarks used to plot its position.

In an effort to compensate for or minimize this error in localization because of unpredictable anatomical variations, workers in the field of stereotaxic surgery have used various physiological methods to obtain a more precise identification of the deep structures involved in the projected lesion or of other neighbouring structures which it is desirable to avoid.

In our modest series of stereotaxic operations for the treatment of involuntary movements at the Montreal Neurological Institute, we have found such physiological exploration of the area in which we planned to make our lesions an extremely useful if not indispensable tool. In this presentation, we shall report on the results of this exploration in 26 procedures carried out on 22 patients.

Material and Method

Of the 22 patients, 15 were operated upon for various forms of parkinsonism, 1 for infantile hemiparesis with athetosis, 1 for multiple sclerosis with paraplegia and severe intention tremor of the arms and trunk, 2 for dystonia musculorum deformans, 2 for chorea, and 1 for multiple tics. In all cases we used the Leksell stereotaxic instrument and, except in 4 of the early cases in which the operation was done in one stage, the apparatus was slightly modified in such a way that the procedure could be carried out in two separate stages. The first one consisted in the application of the stereotaxic frame followed by double contrast ventriculography (Ethiodan* and air) to outline the anterior and posterior commissures of the 3rd ventricle. In the second stage, done a few days later under local anesthesia, the frame was reapplied and, after stimulation or recording in the target area, the operative lesion was carried out with a wire-loop leucotome of the type described by Bertrand.1 When fully extruded, the wire in our leucotome extends in an arc approximately 6 mm. in radius so that when the leucotome is rotated on its axis, it can be expected to make a lesion of approximately 0.9 cc., in the shape of a pear or inverted top.

In 25 of the 26 operations which form the basis of this presentation, the therapeutic lesion was carried out in the region of the nucleus ventralis lateralis of the thalamus or at the junction of this nucleus with nucleus ventralis posterior and in contact with the posterior limb of the internal capsule. In the remaining case, the lesion was aimed at the medial portion of the globus pallidus and the ansa lenticularis.

In these cases and in others, various methods of electrical stimulation and recording (straight multipolar electrodes, chronically implanted leads and more recently microelectrodes to record single-unit potentials) were used in an effort to identify

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* British Drug Houses.
Fig. 1. From left to right. Multipolar ring electrode. Curved searching electrode shown with stimulating tip fully extruded. Wire-loop leucotome and straight needle used to deposit small stainless-steel marker at lowermost portion of lesion at end of the procedure. These instruments all penetrate through a single brain puncture.

better the structures we planned to destroy and others in their neighbourhood. In the group under study, however, we used mainly a curved searching electrode made of a spring wire insulated except at its tip and arranged in such a way that it can be pushed out laterally from the shaft along a slightly curved path to a distance 11 mm. from the axis of the shaft (we claim no originality for this instrument). Like the leucotome, the shaft is made of #16-gauge stainless-steel tubing but the insulated wire-electrode measures are slightly less than 1 mm. in diameter. The tip of this searching electrode can therefore explore in various directions to a distance 5 mm. beyond the reach of the leucotome wire (Fig. 1).

This monopolar electrode was used against an indifferent lead attached to the patient’s ipsilateral leg which also served as ground lead for the cautery. Most of the stimulations were carried out with trains of square waves of 2 msec. in duration at a frequency of 60 per sec. and at amplitudes which seldom exceeded 4 V. With the searching electrode, the peak current was monitored at 0.3 mA. per V. Stimulations lasted between 1 and 5 sec.

After operation, an optical bench consisting of a zirconium arc as a source of light, a stand for the Leksell stereotaxic instrument and a transparent plastic screen were used to trace on paper the position of each point stimulated and of the assumed therapeutic lesion. Since the relative position of the source of light, the stereotaxic frame and the plastic screen on the optical bench were rigorously the same as those of the roentgenographic tube, frame and plate, at the time of operation the tracings obtained of the position of the electrode could easily be superimposed on the films outlining the ventricular system and obtained at the first stage of the operation. The coincidence of the tip of the shaft of the electrode, as outlined on this tracing with a small stainless-steel marker introduced at the end of the operation in the deepest portion of the lesion and visible on a set of anteroposterior and lateral films done before removing the frame, served as a control on the accuracy of the tracing procedure (Figs. 2 and 3).

From these tracings done in the anteroposterior and lateral projections, it was then easy to give each point stimulated along the path followed by the curved searching electrode its coordinates in the three planes of space. The planes of reference were the midsagittal vertical plane, the horizontal plane passing through the center of the anterior and posterior commissures and a coronal plane perpendicular to the other two and passing through a point halfway between the anterior and the posterior commissures. It is estimated that the accuracy of the coordinates plotted for each of the points stimulated should be within 2 mm. of the actual coordinates of that point in vivo.

**Results**

The effect of electrical stimulation, at the parameters used, on the tremor and rigidity of parkinsonism and on other types of involuntary movements was most unpredictable. Although tremor and rigidity were diminished frequently by the mere introduction of the shaft of the stimulating electrode at target, stimulating within the proposed lesion sometimes enhanced and sometimes decreased the tremor. And, indeed, restimulation of a point which had
produced an increase in tremor at one time occasionally reduced it the second time. When active movements were produced, tremor and resistance to passive movements were also modified but we found no area in which tremor could be activated consistently or inhibited by electrical stimulation.

Stimulation within our thalamic target, generally centered 15 mm. from the midline and 5 mm. above the junction of the anterior two-thirds with the posterior one-third of the intercommissural line, most often produced nothing detectable clinically or else the patient reported mild sensations in the face or in the rest of the body, particularly as one approached the posterior limit of the planned lesion. Beyond this limit, in a posterior direction, one almost invariably produced sensation even with currents of less than 1 V. Most patients described these sensations as a "tingling," "pins and needles," a "numb feeling" or as "an electric shock" or "electricity." Occasionally, a feeling of warmth or even a burning sensation was described; more rarely, a cold sensation. With stimuli of intensities above threshold, the sensation usually was described as involving the opposite side of the body and face in a diffuse manner, but with threshold stimuli, more restricted areas were involved such as one cheek, the dorsum of the hand, etc.

When the stimulating electrode was extruded in a lateral direction from its point of insertion, motor responses in the opposite side of the body and extremities became apparent with stimuli of decreasing intensities as the tip of the electrode came closer to the expected position of the internal capsule. When the electrode was thought to be within this structure or, more precisely, amongst the fibres of the corticobulbar and corticospinal pathways, discrete movements could be obtained with stimuli of 60 per sec. at 0.5 or 0.3 V. Under these circumstances, the movements obtained were not unlike those produced by stimulation of the pre-central motor cortex as they could be restricted to a small group of muscles such as one side of the tongue, the corner of the mouth, flexion or extension of a single digit in the hand, or plantar flexion of the foot. Occasionally, discrete movements were also noted at the root of the opposite upper or lower limb, in the neck, or even in the abdominal musculature but the least rise in intensity of the stimulus would usually bring on contraction of other muscles with the production of more complex movements or postures such as something like "main d'accoucheur" with coning of all the fingers or movements in more than one territory. These responses also could be produced by
single shocks delivered at the rate of 1 or 2 per sec., in which case the same muscles responded with brief clonic contractions but at a slightly higher threshold. Any change in the position of the stimulating electrode, even by a millimeter, considerably modified the response which might then involve an entirely different set of muscles or even a different extremity. This convinced us that in spite of the use of monopolar stimulation, effective spread of current must be limited only to the immediate vicinity of the electrode and the localization of the excitable structure must therefore be very precise.

All movements involving the extremities were contralateral but, in a few instances, it also was possible to see contractions on the ipsilateral side of the face but always associated with contractions of the opposite side and always of a lesser amplitude. (In a subsequent case, not included in this series, we have observed once, ipsilateral movements of the orbicularis oculi only, without detectable movement of the contralateral musculature.) Responses of the muscles of the trunk also seemed to be contralateral, at least by simple observation.

In any given case, if the searching electrode was withdrawn, the shaft rotated and the electrode extruded again gradually in such a way as to explore other directions anterolateral or posterolateral to the thalamic target, a somatotopic arrangement of the excitable structures within the presumed area of the internal capsule became noticeable. Motor responses in the face and tongue were obtained in greater numbers in front of the zone that yielded responses in the arm and hand whereas responses in leg and foot were seen somewhat more posteriorly. Some of the points which produced motor responses also produced sensations and the sensory responses also tended to be more frequent posteriorly. They were not described differently from the ones mentioned earlier.

Fig. 4 represents the various points stimulated in our Case 21. For the sake of simplicity, all points are plotted on a single horizontal plane although they ranged from levels 4 mm. above the intercommisural plane to levels 3 mm. below the same plane. These various points have been drawn on a diagram taken from part of horizontal section H.d+1.5, plate 55, of the stereotaxic atlas by Schaltenbrand and Bailey9 (Fig. 6). They represent a composite picture of 6 separate runs of stimulation carried out in various directions and at two different levels. From this it can be seen that low-threshold (1 V. or less) facial motor responses were obtainable at points ranging from 18 to 22 mm. lateral to the midsagittal plane and from the midcommisural coronal plane to approximately 3 mm. behind that plane. Movements of the leg also were produced within the same area but somewhat more laterally. Various sensations were produced by stimulations along a line running backwards and sagittally 16.5 mm. from the midline and extending to a point 13 mm. behind the midcommisural plane. Sensations also were produced more laterally at points that yielded movements in the arm and leg but not where movements of the face were obtained. From these results, it seemed apparent that a lesion centered as it was in this case, 5 mm. behind the midcommisural coronal plane, could not be extended much more than 18 mm. from the midline in a lateral direction without impinging on the corticobulbar and corticospinal fibres and that destruction should also be done carefully in the posterior quadrants to avoid damage to important sensory structures.

Fig. 5 is a composite diagram of all the points stimulated in 26 operations for which accurate plotting was possible. We have shown here only points from which motor responses were obtained at low threshold, that is, with 1 V. or less. We also have shown points at which no response could be detected with stimuli of 3 V. and sometimes more. These are represented again on the same horizontal plane as Fig. 4 although they are in fact scattered somewhere between the +5 mm. and the −3 mm. horizontal planes.

In spite of the number of cases and of the fact that no correction was applied for
Fig. 4. Part of horizontal section Hl. +1.6 (plate 55) of the stereotaxic atlas by Schaltenbrand and Bailey⁹ (rectangle outlined by dotted line in our Fig. 6) on which have been outlined the points stimulated in our Case 21. (Points scattered in horizontal planes +4 mm. to −3 mm. inclusive.) Each square measures 10X10 mm.
FIG. 5. Same section as Fig. 4 on which is shown the distribution of points producing motor responses with stimuli of 1 V. or less (coloured dots) and other with no response to stimuli of at least 3 V. (black dots). (Points scattered in horizontal planes +5 mm. to −3 mm. inclusive.)
individual intercommissural distances or the width of the 3rd ventricle, the grouping of the responses remains surprisingly good although there is more overlap between the areas controlling responses of the face, arm and leg. Surprisingly few motor responses were obtained in front of the midcommissural coronal plane and, actually, most of the responses plotted there belong to a single case, a boy of 8 with a rather small head, the only child in this series. Although exploration has not been quite so extensive in that area, stimulation in the region of the anterior half of the posterior limb of the internal capsule yielded no motor or sensory responses, except in the case of the small boy. In the 21 other patients, responses in the face and tongue were always obtained well behind the midcommissural plane in the area of the capsule which lies medial to the lateral portion of the globus pallidus. Most of the responses in arm and hand were elicited in the retrolenticular portion of the internal capsule and showed considerable overlap with the points from which movements of the lower extremities were produced. Movements of the neck and trunk were obtained in various points distributed within the entire “motor” area but, in individual cases, the responses of the neck were produced from points slightly more anterior than movements of the lower trunk. It is also noticeable that the points of “negative response” are very few in this area.

Fig. 8 is a diagrammatic representation of 16 separate runs of stimulation in which it was felt that the “motor” area of the internal capsule had been traversed from one side to the other. Each bar shows the distance over which low-threshold motor responses were obtainable, that is, motor responses at 1 V. or less. Again, these are plotted on a single horizontal plane although the actual responses may have been obtained from anywhere between plane +5 mm. and plane −4 mm. The shortest of these runs, from Case 11, was only 2 mm. long and is again from the young boy, whereas the longest run measured 8 mm. but is oriented almost parallel with the long axis of the capsule and therefore remains well within it. The others averaged approximately 5 mm. which is what one would expect from an anatomical measurement of the capsule. This finding suggests that the motor fibres are probably scattered through most of the width of the internal capsule at that level. Four of these runs had their medial limit 17 mm. only from the midline. Most of them started at 18 or 19 mm. and in one case motor responses were not obtained until the electrode reached 22.5 mm. from the midline (Case 7). In this particular run, low-voltage stimulation still produced movements in the hand and face at slightly more than 26 mm. from the mid-sagittal plane. In this patient, the 3rd ven-
Fig. 7. Distribution of sensory responses obtained at 1 V. or less (same section as Figs. 4, 5 and 8; points scattered between horizontal planes +5 mm. and −2 mm. inclusive).
tricle, as seen on the films, measured 8 mm. across (corrected), the widest in this series. This seems to confirm the fact that the presence of a wide 3rd ventricle may displace the internal capsule laterally and should be taken into consideration when plotting the coordinates of a thalamic target. In all the other cases, when the mesial and lateral limits of the "motor" pathways were determined, the width of the 3rd ventricle did not exceed 5 mm. and corrections for this did not significantly diminish the scatter.

Fig. 7 outlines on a similar diagram the various points from which low-threshold sensory responses were obtained. Again, points stimulated at various levels have been compressed into a single horizontal plane which makes the identification of the structure stimulated extremely difficult since this area lies at the junction of the thalamus and subthalamus. We have not studied these responses in detail yet but they serve to fill in the blank areas and accentuate the fact that the motor pathways seem to occupy a very restricted zone far back in the posterior limb of the internal capsule. It also shows some scattering of sensory structures amongst the motor pathways, with a tendency for denser grouping posteriorly. In the area where the thalamic lesions have usually been made, and directly behind this zone, there seems to be some somatotopic arrangement of the sensory structures and one cannot help being struck by the fact that the facial sensations were produced most often between coronal planes P-4 and P-10 while sensations of the leg and foot appeared almost exclusively behind plane P-11 with responses of the arm and hand scattered more diffusely. We feel that this somewhat unexpected somatotopic arrangement is probably the result of stimulation across sensory fibres running obliquely from their thalamic nuclei to join the posterior limb of the internal capsule on their way to the sensory cortex.

Discussion

No agreement has been reached as yet concerning the exact mechanisms responsible for the tremor, rigidity and bradykinesia of parkinsonism or for the different types of involuntary movements seen in other extrapyramidal diseases. We are still very ignorant also of the exact nature of the structures, the surgical destruction of which abolishes the abnormal movements and restores a more nearly normal tone of muscle. This study certainly sheds very little additional light on these problems and it is outside the scope of this presentation to discuss them fully. The lack of anatomical confirmation of the exact location, size and shape of our therapeutic lesions, for which we must be thankful in a sense, together with the unpredictable individual variability in location of the deep cerebral structures, have made it difficult to know precisely what is involved in the lesion in terms of nuclei and larger fibre tracts, to say nothing of the microscopic elements
themselves which are all destroyed without
discrimination.

We have felt that the use of electrical
stimulation by means of a curved searching
electrode which could probe in various direc-
tions in and around the projected lesion
added a small measure of precision to our
operative technique and its use has given us
additional confidence in guiding the place-
ment and shape of the lesion which we felt
should extend laterally very close to the cor-
ticobulbar and corticospinal pathways with-
out actually encroaching upon them. Gros et al.,
who recently described a similar tech-
nique of stimulation with comparable results,
also have come to the same conclusion.

The sudden marked diminution or even
complete disappearance of tremor and
rigidity, which has often occurred when the
shaft of the electrode penetrated the last
centimeter of tissue which formed the central
core of the projected lesion, coupled with the
fact that discrete motor responses in the
face, arm and leg could not be obtained until
the searching electrode subsequently had
been extruded and sometimes 8 mm.
farther laterally, seem to bring confirmation
to the fact that the effectiveness of the
therapeutic lesion did not depend on de-
struction of the corticospinal or corticobulbar
fibres or of other descending fibres in the
internal capsule.

The frequent occurrence of sensory re-
sponses to stimulation within the area of the
lesion, particularly in its posterior extent,
and the fact that the progressive enlarge-
ment of the lesion in this area, as it is
produced quadrant by quadrant with the
leucotome, often seemed to bring on more
dramatic modifications of the tremor than the
anteriorly placed quadrants, have also
led us to wonder if sensory pathways did not
play an important role in the tremorogenic
mechanism.

Electrical stimulation within what we
have thought to be the internal capsule itself
also has produced interesting information on
the localization of the motor pathways
within that structure. The classical repre-
sentation of the corticobulbar and cortico-
spinal pathways on a horizontal section of
brain which also includes the globus pallidus
and thalamus shows the motor fibres to the
face and mouth at the genu of the capsule.
The fibres to the arm and hand are situated
somewhat farther back in the posterior limb
of the capsule and the fibres to the leg form a
separate contingent still farther behind, ap-
proximately opposite the posterior limit of
the lateral portion of the globus pallidus.
This arrangement is reproduced even in very
recent neuroanatomical textbooks and is
derived from studies by Dejerine who,
in 1901, followed the degenerated fibres from
fairly restricted lesions in the motor cortex.
In 1958, however, Guiot et al. pointed out
from the results of their own stereotaxic
stimulations that the motor pathways and
particularly the corticobulbar pathways
were actually to be found much farther back
in the posterior half of the posterior limb of
the internal capsule and not at the genu or in
the portion of the capsule immediately be-
hind it. Similar conclusions have been
reached since by Gillingham, by Gros et al.,
and by Orthner et al. Bertrand and Mar-
tinez also have pointed out that lesions can
be made in an area which was calculated to
be at the junction of the anterior and middle
thirds of the posterior limb of the internal
capsule with the production of only transi-
tory motor signs rather than a hemiplegia as
one could have expected from the classical
anatomical descriptions. Necropsy studies
by Smith on the brains of patients operated
upon for parkinsonism have brought further
confirmation of this finding.

Our data on stimulation support all this
evidence and may be summarized in Fig. 6
which outlines schematically the area in
which one can expect to find the motor fibres
for face, arm and leg. They seem to form a
fairly compact bundle with considerable
overlap of fibres subserving adjacent terri-
tories. They appear to occupy most if not all
of the width of the posterior limb of the in-
ternal capsule, in the anterior 8 mm. of its
posterior half.
Although we have not sampled the area of the genu of the capsule, stimulations in regions well in front of the above-mentioned face area have not produced anything detectable apart from an occasional feeling of nausea or slight modifications in the tremor or rigidity. Although we have looked for them, we have not noticed any involuntary movements of the eye or pupillary changes or any obvious vasomotor manifestations. The only modification of speech that we observed always took the form of difficulty in pronunciation coinciding with stimulation-induced movements in the mouth or tongue. We have never produced aphasia. This was so whether the operation was carried out on the dominant or the nondominant hemisphere. Nor have we noticed in the regions explored and with our technique the acceleration or slowing of speech described by Guiot and his collaborators.6

Summary

A method is described of electrical stimulation of deep cerebral structures within and around stereotaxically produced thalamic and pallidal lesions.

The motor and sensory responses to these stimulations are analyzed and their usefulness as a guide to more precise placement and shaping of the therapeutic lesion is discussed. This study also throws additional light on the topographical arrangement of descending motor pathways within the posterior limb of the internal capsule.

References