Arrangement of Pyramidal Tract Fibers in the Internal Capsule of the Rhesus Monkey

By

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Summary: Attention has been drawn to the localization of the pyramidal tract within the internal capsule of the rhesus monkey. This paper is based on experiments with 8 adult rhesus monkeys. An electrode was inserted stereotactically towards the posterior limb of the internal capsule. Its location at the internal capsule was confirmed by inducing movements of the contralateral forelimb with a current of 1 V or less, and the same site was electrocoagulated. Following the operation, the right upper extremity of the experimented animal revealed a characteristic transient paresis. Histological observations indicated that the pyramidal tract which projected the upper limb occupied the anterior third of the internal capsule. However, this conclusion is only acceptable at the horizontal level of the superior limit of the thalamus, since the pyramidal tract changes anatomical location within the posterior limb as it courses through the internal capsule.

For a long time, the pyramidal tract was believed to occupy the anterior half of the posterior limb of the internal capsule, as suggested by Charcot (1893) and Dejerine (1901). This idea was accepted among clinicians and diagrammed by Foester (1931). However, many investigators have recently refuted this conclusion, and stated that the pyramidal tract is located more posteriorly in the posterior limb of the internal capsule (Smith, 1960, 1962; Hirayama et al., 1961; Hanaway, 1977). Such a representation of the pyramidal tract in the internal capsule was based on autopsy data from human brains which had suffered from infarct (Englander et al., 1975; Hanaway, 1977), or amyotrophic lateral sclerosis (Hirayama et al., 1961), and on data of electrical explorations made during stereotactic operations for parkinsonism and hemiparesis (Guiot et al., 1958; Thurel et al., 1961, 1964; Smith, 1960, 1962). However, no definitive anatomical evidence was available about the location of the pyramidal tract in the monkey internal capsule. The question thus arose as to the exact location of the pyramidal tract of the monkey internal capsule. The present study was devised to clarify this question.

Materials and Methods

Experiments were performed on 8 adult rhesus monkeys weighing 3.0 to 3.5 kg.
The animals were anesthetized with pentobarbital sodium (Nembutal, 5 mg/kg), and clamped in a stereotactic instrument. The soft tissues of the left frontoparietal area and the underlying bone were removed to explore the dorsolateral aspect of the left hemisphere. At the site of craniotomy, a concentric electrode of approximately 0.5 mm in outside diameter was inserted towards the posterior limb of the internal capsule stereotactically according to the atlas of Shider and Lear (1961) and the location of the electrode at the internal capsule was confirmed by inducing movements of the contralateral forelimb with a current of 1 V or less. Lesions were produced by passing a direct current of 30 mA, for 60 sec, and then the concentric electrode was removed.

The survival periods after operation were 3-117 days. The experimental animals were sacrificed by perfusion with a mixed solution of 4% paraformaldehyde and 0.25% glutaraldehyde in Millonig’s buffered solution (adjusted to pH 7.20) under pentobarbital anesthesia. After removal of the brain and spinal cord, tissue blocks of the pyramid and each segment of the spinal cord were post-fixed in 2% osmic acid in the same buffered solution, followed by the usual embedding procedure in Epon 812. Semi-thin sections of 1 μm in thickness were stained with toluidine blue or paraphenylenediamine.

On the other hand, the brains were removed and immersed in 10% formalin for adequate periods of time, embedded in celloidin, and cut into 40 μm serial sections. The sections were stained with routine Meyer’s hematoxylin-eosin stain and Yashiro’s myelin sheath stain for identifying precise site and extent of the lesions.

**Results**

Case 1 (M58). After the operation, spastic paresis appeared in the right arm and slightly in the right leg. Such spasticity of motor performance persisted until the animal was killed.

Histological observations. The lesion extended broadly from the genu of the left internal capsule to the anterior two-thirds of the left posterior limb at the horizontal level of the superior limit of the thalamus. It spread dorsomedially to the caudate nucleus, some parts of the thalamus (anterior nuclear group and ventral lateral nucleus) and mammillo-thalamic tract. Furthermore, the globus pallidus and putamen adjacent to the internal capsule were involved to some extent. In this case, the internal capsule was broadly destroyed, but the posterior third of the posterior limb was not lesioned (Text-Fig. 1). Degenerated nerve fibers appeared in the left pyramid above the decussation and were present bilaterally below that region. It was definite but very slight on the left side of the cord, while on the right side it was plentiful and spread throughout the pyramidal tract, although the number of degenerated nerve fibers was reduced below the middle thoracic cord (Plate 1 Fig 1, Text-Fig. 2).

Case 2 (M59). Following the operation, the right upper extremity showed a characteristic transient spastic paresis. Extension, flexion, abduction and adduction of the shoulder absent. After 7 days, recovery occurred and normal movements were performed until the animal was sacrificed.

Histological observations. The main lesion affected the lateral part of the anterior third of the posterior limb of left internal capsule at the horizontal level of the superior limit of the thalamus. The adjoining dorsal part of the putamen...
Abbreviations of Text-Figures

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<thead>
<tr>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>A</td>
<td>Nucleus anterior thalami</td>
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<tr>
<td>Amyg</td>
<td>Amygdala complex</td>
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<tr>
<td>Caud</td>
<td>Nucleus caudatus</td>
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<tr>
<td>Ci</td>
<td>Capsula interna</td>
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<tr>
<td>Cl</td>
<td>Claustrum</td>
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<tr>
<td>Co. ant</td>
<td>Commissura anterior</td>
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<td>Co. post</td>
<td>Commissura posterior</td>
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<td>For</td>
<td>Fornix</td>
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<td>GM</td>
<td>Nucleus geniculatus medialis</td>
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<td>Globus pallidus</td>
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<td>Ped</td>
<td>Pes pedunculi</td>
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<td>Put</td>
<td>Putamen</td>
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<tr>
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<td>Nucleus ruber</td>
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<td>TMT</td>
<td>Tractus mamilothalamicus</td>
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<td>VPI</td>
<td>Nucleus ventralis posterior inferior</td>
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<tr>
<td>II</td>
<td>Tractus opticus</td>
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<td>II Ch</td>
<td>Optic Chiasma</td>
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<td>III</td>
<td>Ventriculus tertius</td>
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Text-Fig. 1. Case 1 (M58). Schematic representation of the lesion of the brain in the frontal section. In this case, the left internal capsule is broadly destroyed, but the posterior third of the posterior limb is not lesioned.
Text-Fig. 2. Degeneration of the spinal cord in the Case 1 (M58). Degenerated fibers are represented by dots. Most of fibers constitute the crossed lateral pyramidal tract, while a small number of degenerated fibers constitute the uncrossed lateral and ventral pyramidal tracts.
and the dorsolateral part of the caudate nucleus were also involved (Text-Fig. 3). The left pyramid was heavily degenerated, the degeneration being situated in the central part of the left pyramid near its ventral border, occupying an oval area which tapered slightly in the medial direction. In the cervical cord, there was a less-marked patch of degeneration in the right lateral column occupying an
irregular triangular area in the posterior part of that column. A few degenerated nerve fibers were scattered in the left lateral and ventral columns.

Case 3 (M60). After the operation, the right hand showed transient flaccid paralysis. The other symptoms were slight muscular weakness on the affected side and some preference for use of the normal hand. Two weeks later, slight improvement had appeared in the use of the affected hand.

Histological observations. The lesion involved the anterior third of the posterior limb of the left internal capsule at the horizontal level of the superior limit of the thalamus, and extended into the caudate nucleus, anterior nuclear group and ventral lateral nucleus of the thalamus adjacent to the internal capsule (Text-Fig. 4). Degenerated myelinated fibers could be traced into the lumbar cord. In the ventral funiculi of the spinal cord, there were few degenerated fibers.

Text-Fig. 4. Case 3 (M60). Schematic representation of the lesion of the brain in the frontal section. In this case, the lesion involves the anterior third of the posterior limb of the left internal capsule, and extends into the caudate nucleus, anterior nuclear group and ventral lateral nucleus of the thalamus adjacent to the internal capsule.
Case 4 (M62). Following the operation, the animal exhibited a characteristic flaccid paresis of the right hand and shoulder. Recovery took place during the first 2 weeks and normal movements were performed until the animal was sacrificed.

Histological observations. The most rostral portion of the posterior limb of the internal capsule, and adjacent caudate nucleus were both included in the lesion (Text-Fig. 5). Heavy degenerated fibers occupied the central portion of the left pyramid. Examination of the cervical cord revealed that bilateral degeneration of fibers was limited and widely scattered. On the right side, there was much degeneration. The number of the degenerated fibers on each side below the mid-thoracic cord was insignificant.

Case 5 (M57). After the operation, and abduction of the right hand were absent. Decreased resistance to passive movements of the right wrist were poorly used.

Histological observations. The lesion was more or less limited to the most rostral portion of the internal capsule at the horizontal level of the superior limit of the thalamus. The reminder of the internal capsule was normal, but there was minimal damage to the head of the caudate nucleus and cingulate gyrus.

Text-Fig. 5. Case 4 (M62). Schematic representation of the lesion of the brain in the frontal section. In this case, the most rostral portion of the posterior limb of the internal capsule, and adjacent caudate nucleus are both included in the lesion.
(Text-Fig. 6). In the left pyramid, a heavy bundle of the degenerated fibers occupied about half of the entire area, being placed medially from the center. The spinal cord from cervical to thoracic levels showed marked coarse degeneration of the right lateral column and slight degeneration of the left one. The ventral funiculi were not definitely changed.

Case 6 (M51), 7 (M53), 8 (M54)

After the operation, on these cases, any motor disorder had not appeared.

Histological observations. In the case 6 (M51), the reticular nucleus, anteroventral nucleus, and anterior nuclear group of the thalamus were destroyed, but the internal capsule was not involved in the lesion (Text-Fig. 7). In the case 7 (M53),

Text-Fig. 6. Case 5 (M57). Schematic representation of the lesion of the brain in the frontal section. The lesion is limited to the most rostral portion of the internal capsule. The reminder of the internal capsule is normal, but is minimal damage to the head of the caudate nucleus and cingulate gyrus.
Text-Fig. 7. Case 6 (M51). Schematic representation of the lesion of the brain in the frontal section of the brain. The reticular nucleus, anteroventral nucleus, and anterior nuclear group of the thalamus are destroyed, but the internal capsule is not involved in the lesion.

the lesion of the internal capsule was limited in the anterior limb. Furthermore, a portion of the caudate nucleus was lesioned (Text-Fig. 8). In the case 8 (M54), there was no lesion in the brain parenchyma. However, hematoma appeared in the precentral and postcentral gyri opposed to the part of the craniotomy (Text-Fig. 9).

Discussion

In the present study, lesions which caused to the paresis of the anterior limb were formed in the anterior third of the posterior limb of the internal capsule at the horizontal level of the superior limit of the thalamus and adjacent structures including the caudate nucleus and putamen,
Text-Fig. 8. Case 7 (M53). Schematic representation of the lesion of the brain in the frontal section of the brain. The lesion of the internal capsule is limited in the anterior limb. Furthermore, a portion of the caudate nucleus was lesioned.

but the posterior third of the internal capsule at the same horizontal level was not destroyed. Semidiagrammatic representation of the lesions in all experimental animals is given in Figure 10. Histological observations of the pyramid and spinal cord revealed that the degenerated fibers occupied the region ascribed to the pyramidal tract system. From the above findings, it appeared that there was a
positive correlation between the lesions in the anterior third of the posterior limb and degeneration of the pyramidal tract system.

It has long been believed that the pyramidal tract system within the internal capsule occupy the anterior third of the posterior limb (Bennet and Campbell, 1885; Charcot, 1893; Dejerine and Dejerine-Klumpke, 1901). However, many authors have recently disputed this traditional localization of the internal capsule. For example, Hirayama et al. (1961) observed that in the horizontal sections of the internal capsule from 3 cases of amyotrophic lateral sclerosis, the changes were localized in the third region from the anterior end when the posterior limb was
divided into 4 equal parts. The changes in this region were characterized by an absence of fibers of large caliber. Englander et al. (1975) reported that the human pyramidal tract was located in the third quarter of the posterior limb of the internal capsule. This description was based on a patient with a small infarct located posteriorly in the internal capsule who had 9 years of weakness of the contralateral face, arm, and leg.

Studies using electrophysiological stimulation of the deep structures of the brain during stereotactic surgery for motor disorders indicated that the pyramidal tract was located in the posterior half of the posterior limb. For example, Bertrand (1966) using electrical stimulation with a curved searching electrode found that the motor pathways were a long way from the genu of the capsule. Gillingham (1962) plotted the site and extent of the lesions of the globus pallidus, thalamus, and adjacent internal capsule for the relief of the Parkinsonism on stereotactic anatomical charts. He found that the motor fibers were concentrated laterally and posteriorly within the posterior limb of the internal capsule. According to the surgical studies of Thurel et al. (1961; 1964), the pyramidal tract was located in the posterior limb of the internal capsule.

Smith (1962) described the stereotactic lesions in 15 brains of patients with Parkinson's disease, Hunchington's chorea or semichorea, and demonstrated that the internal capsule was frequently involved but it was rare for this to result in serious paralysis. He did not specifically address the question of the pyramidal tract.
localization, but his illustrations indicated that the pyramidal tract was not confined to the anterior half of the posterior limb of the internal capsule. According to another paper by him (1960) on cases of amyotrophic lateral sclerosis, the corticospinal tract was highly localized within approximately one sixth of the posterior limb in its middle part.

Such evidences above suggested that the pyramidal tract actually resided in the posterior half of the limb. However, Rottenberg et al. (1976) opposed this idea. They published a report of a patient with a lesion in the posterior portion of the posterior limb which resulted from a metastatic tumor, who failed to reveal any evidence of contralateral hemiparesis. However, in their report, there was regrettably no anatomical evidence on secondally degeneration of the pyramidal fibers.

Anatomical evidence about the localization of the pyramidal tract within the internal capsule has thus been accumulated in the past two decades, but the data were mainly on human clinical cases. There have been few descriptions of its localization within the internal capsule in monkeys. Beevor and Horsley (1890) in their electrical stimulation studies on motor localization in the posterior limb corresponding to the cortical sequence of face anterior, arm intermediate, and leg posterior. In the study of Grees and Cole (1950) on the pyramidal tract of the monkey the lesions were made in the thum area of the motor cortex. They observed the degenerated myelinated fibers did not pass the internal capsule as a circumscribed fiber bundle but were widely scattered throughout the genu and posterior limb. Schafer (1883) found after ablation of the frontal cortex of macaques that a number of fibers in the central part of the internal capsule degenerated; these were not closely packed together, but were somewhat scattered. The work of Bernard et al. (1956) indicated that fibers from the leg area were seen in the intermediate and posterior parts of the posterior limb. In general, these results agreed with the findings of Levin (1936) in that capsular fibers from more rostral cortex occupied a position more medial and more rostral than projections from more caudal cortex. Kennard (1935) concluded that the chief degeneration after lesions of the motor cortex of monkeys was located at the genu of the internal capsule. As in human cases, the reported localization of the pyramidal tract within the internal capsule of the monkey varied among different investigators.

In an attempt to resolve this conflict, Ross (1980) dissected out the pyramidal tract and found that it entered the internal capsule in the anterior half of the posterior limb and shifted progressively into the posterior limb in more caudal horizontal sections. His results indicated that the human pyramidal tract did not maintain a fixed position in the internal capsule. On this basis, it seems reasonable to find that the pyramidal tract occupied the anterior third of the posterior limb at the horizontal level of the superior limit of the thalamus in the present study, the middle portion of the posterior limb at the horizontal level of the middle point of the thalamus (Fisher and Curry, 1965), and the third quarter of the posterior limb at the horizontal level of the lower limit of the thalamts (Brion and Guiot, 1964).

References

2) Beevor, C.E. and Horsley, V.: Experimental investigation into the arrangement

3) Bennett, A. H. and Campbell, C. M.: Case of brachial monoplegia due to lesion of the internal capsule. Brain, 8: 78-84, 1885.


Arrangement of Pyramidal Tract Fibers in the Internal Capsule

PLATE
Explanations of Figures

Plate I

Fig. 1. Degeneration in the pyramidal tract in the Case 1 (M58). There is heavy degeneration in the left pyramid above the decussation (a). In the spinal cord (C-2 segment), degenerated myelinated nerve fibers are observed in the right lateral funiculus (b), left lateral funiculus (c), and bilateral ventral funiculi (d). All bars represents 50 μm.