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Abstract

An anatomical study was made to follow the degeneration of fibers by means of Marchi technique in cat after making experimentally lesion in Forel H field. As the results the following conclusions were reached. 1) The ipsilateral distribution of the degenerated granules was in the anterior sigmoid gyrus, caudate nucleus, putamen and globus pallidus, thalamic nuclei medial to the internal medullary lamina, substantia nigra, rubrocerebellar system, medial longitudinal fascicle system, mesencephalic and pontine reticular formation and medial lemniscus. 2) There was also contralateral distribution to the interpositus and dentatus nuclei of the cerebellum via brachium conjunctivum, to globus pallidus via supraoptic commissure, to subthalamic region and substantia nigra via supramammilary commissure, and to red nucleus via tegmental decussaion. 3) The degeneration is so extensive that the Forel H-field seems to be the cross road of the extrapyramidal system in association with brainstem activating system.

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FIBER CONNECTIONS OF THE FOREL H-FIELD AS SEEN IN MARCHI PREPARATIONS

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There has been a progressive number of anatomical and physiological research works in the extrapyramidal system. Amongst them, to a part of the subthalamic region, the Forel H-field, a special attention has been paid by JINNAI and his co-workers[16], based on their experimental findings that it plays a great role as the conduction pathway of the corticogenic convulsion. Physiological approach revealed that the Forel H-field is composed of the main axis of cortico-subcortical reverberating circuit, and the lesion causes a decrement in the excitability of the cortex and an inhibition of the corticogenic epileptic convulsion (in press, 22).

In this experiment, anatomical analysis was attempted to study fiber connections of the Forel H-field by the Marchi degeneration technique. There are found several anatomical investigations of the subthalamus[11,17,15,28,30,31] since Forel's description of the "H Feld"[13], but no report is based on the degenerated fiber study at the H-field lesion itself or concerned with the anatomy of the H-field proper.

MATERIALS AND METHODS

Based on the experiment of 5 cats of which the subthalamic region was lesioned in part, an analysis was made on 2 out of them whose unilateral Forel H-field was histologically successively destroyed. The animals were unmobilized at a stereotaxic apparatus under Nembutal anaesthesia and a constant direct current, 4 mA, was used for 45 sec in order to make anodal coagulation of the Forel H-field through a 0.75 mm in diameter, electrically insulated except the tip, stainless steel needle, which was inserted at right angle to the horizontal plane formed by bilateral infraorbital edges and external meati. A football-shaped lesion was histologically verified to be composed of the two parts; the inner part was a coagulated defect and the outer part an absolutely necrotized

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hard shell. The lesion was 1.0-1.5 mm in diameter and 1.5-2.0 mm in height. Sixteen days were allowed postoperatively for survival period. Brains were perfused by 10% formalin solution through bilateral carotid arteries under Nembutal anaesthesia before it was taken out of the skull, and made for the Marchi preparations.

During the survival period, the observation did not reveal any specific neurological and behavioral abnormality in C-47, but torticolis-like posture or counterclockwise head turning to the observers was found in C-46.

RESULTS

Snider and Niemer's atlas[32] was referred to. According to it, the centres of the lesions in both cats were located in A : 7.5 ; the one of C-46 was, in precise sense, 0-0.5 mm anterior to the one of C-47 (Figs. 1 and 2). Histological observation revealed almost the same degeneration pattern in both cases, but the positive degeneration at *fasciculus longitudinalis medialis* was seen only in C-46.

This animal was selected for illustration.

Degeneration was looked upon both directions, anterior and posterior to the lesion (A : 7.5). Interaural section is AP : O and the number is mm in unit.

Plate II, 3 (A : 7.5) Two groups of degenerated granular concentration of large and fine calibers are found mediodorsal and laterodorsal to the lesion. The former group is continuous dorsally with the granules in parafascicularis and centralis centralis nuclei of the thalamus along habenulointerpeduncular tract and medially with scattered fine granules at the posterior hypothalamic nucleus. It forms ventromedially the Forel's supramammilary decussation which crosses the midline into subthalamic region of the opposite side ; the Forel H-field, zona incerta and subthalamic nucleus. The latter forms laterally a thick granular stream (H 1), running through the external medullary lamina. It forms laterally a scattered fine granular stream into zona incerta. In addition to them, the third ventrolateral group covers the dorsal edges of subthalamic nucleus and pes pedunculi and sends some of the gran ules into the subthalamic nucleus.

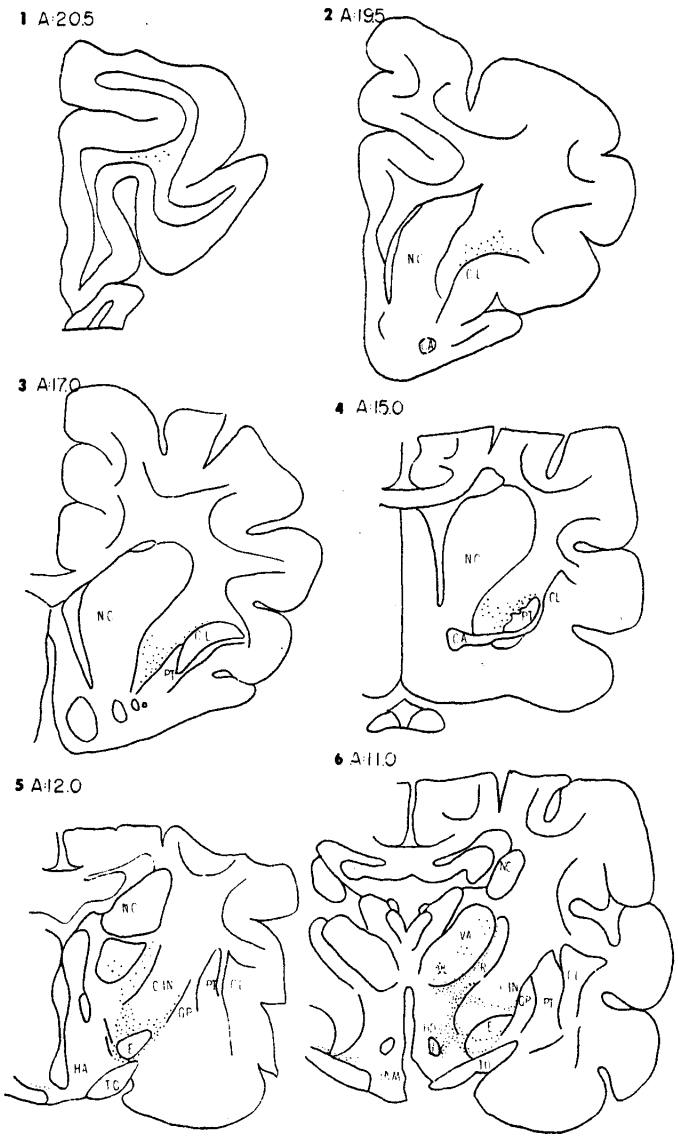
Plate II, 2 (A : 8.0) Four groups of granular stream are found around the lesion ; mediodorsally into the centralis medialis nucleus of the thalamus and posterior hypothalamic nucleus, dorsally into parafascicularis and centralis centralis nuclei of the thalamus, dorsolaterally through H1 and external medullary lamina with branches of scattered granules into ventroposteromedialis and ventroposterolateralis nuclei of the thalamus, and lateroventrally along the dorsal edge of subthalamic nucleus and pes pedunculi (H2) with a branch into the subthalamic nucleus.

Plate II, 1 (A : 10.0) Granular concentration is mainly found in two areas. One is of a dense granulation of both large and fine calibers at the middorsal area of the subthalamic region with two major streams on lateral direction, the dorsal stream (H 1) is continuous with the fine granules in ventralis medialis, ventralis lateralis and ventroposterolateralis nuclei of the thalamus, and also reticularis nucleus through the external medullary lamina, and the ventral stream (H2) runs transversely through the internal capsule. On the other hand, a diffuse granulation is found medial to pes pedunculi which sends streams medially into hypothalamus and laterally towards lenticular ansa around the medioventral edge of pes pedunculi and also through the internal capsule and entopeduncular nucleus. Attention is to be paid on the facts that there is a large granular stream along lenticular ansa of the opposite side, and also that there could not be found any degenerated granules at the thalamic nuclei medial to the internal medullary lamina.

Plate I, 6 (A : 11.0) There are two major areas of granulation, dorsal to pes pedunculi and ventral to thalamus, between which fine granular bridge is formed. The former runs medially around the ventromedial border of pes pedunculi and then ventrally in lateral hypothalamus lateral to fornix, where some of them branch off medially to form pallidohypothalamic fascile and laterally to form lenticular ansa through and around entopeduncular nucleus. In addition to them, a stream traverses through internal capsule directly from the major area to reach the medial border of globus pallidus. The granules in the latter area run dorsolaterally along the medial border of reticularis nucleus of the thalamus. Fine granulation is found in ventralis medialis, ventralis lateralis and ventralis anterior nuclei of the thalamus. There are again the same findings as seen in the previous section ; granulation of lenticular ansa of the opposite side and no graulation in the thalamic nuclei medial to internal medullary lamina.

Plate I, 5 (A : 12.0) Granular concentration is found at the area mediodorsal to entopeduncular nucleus, which streams laterally through the internal capsule onto the medial border of globus pallidus and also medioventrally around the medioventral edge of entopeduncular nucleus towards globus pallidus (lenticular ansa). Having granular bridge with the concentration, fine granular

Plate I.


1 A:20.5
2 A:19.5
NC
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3 A:17.0
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PT
4 A:15.0
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5 A:12.0
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VA
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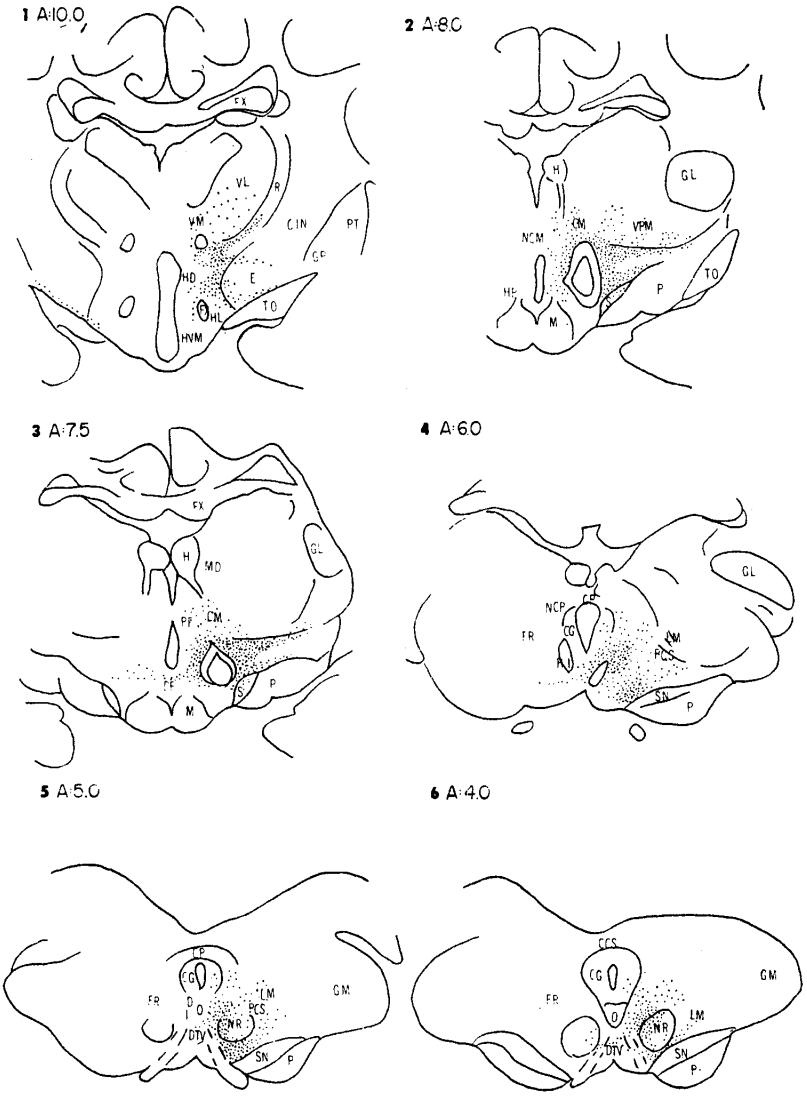
Plate II.


1 A:10.0
FX
VL
R
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CIN
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CP
HD
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HL
TO
HVM
2 A:8.0
H
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CM
VPM
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P
TO
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3 A:7.5
FX
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PF
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4 A:6.0
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stream in ventralis anterior and reticularis nuclei of the thalamus as far as the ventral edge of caudate nucleus. Granulation is found along supraoptic commissure.

Plate I, 4 (A : 15.0) This section is just rostral to globus pallidus, and putamen faces to internal capsule with its medial border. Scattered granules are observed in internal capsule between caudate nucleus and putamen, and fairly concentrated along the medial border of the putamen.

Plate I, 3 (A : 17.0) Granules of large and fine calibres are found in internal capsule along the dorsal edge of putamen and claustrum as well as in capsula extrema. They diffuse away towards caudate nucleus at its ventrolateral edge.

Plate I, 2 (A : 19.5) There are granules in internal capsule, medial and dorsal to claustrum.

Plate I, 1 (A : 20.0) Scattered granules are found in the white matter of anterior sigmoid gyrus.

Now the posterior sections to the lesion are to be looked upon.

Plate II, 4 (A : 6.0) There are two major groups of granular concentration ; one is lateral to the habenulointerpeduncular tract at the ventrodorsal level of oculomotor nucleus and the other is mediodorsal to substantia nigra. The former is medially continuous with the diffusely scattered granules in oculomotor nucleus, central gray, Darkschewitsch nucleus and interstitial nucleus, and also with the ones towards red nucleus, zona incerta and substantia nigra of the opposite side, positively through ventral tegmental decussation. Dorsally it spreads into posterior commissure and its nucleus, laterally into reticular formation, including superior cerebellar peduncle and ventrally diffusely overlapped into the medial extention of the latter group. Lemniscus medialis is intact.

Plate II, 5 (A : 5.0) There are again two major areas of the granular concentration ; one of large and fine calibres in the mediodorsal part of red nucleus and its outer area sends branches medially along ventral tegmental decussation, mediodorsally into oculomotor, interstitial, Darkschewitsch nuclei and central gray, dorsally into posterior commissure and its nucleus and laterally diffusely into reticular formation, and the other is at the triangle formed by substantia nigra, oculomotor and red nuclei, continuous with the granules in superior cerebellar peduncle. No granulation could be found in the opposite side.

Plate II, 6 (A : 4.0) Granular concentration is observed in the mediodorsal part of red nucleus and its outer area, which has two major granular streams ; the medioventral stream around the medial border of red nucleus along ventral tegmental decussation and the dense vertical stream into the lateral border of central gray and medial logitudinal fascicle. There are fine granulation in reticular formation. Large granules in the ventral area of red nucleus are continuous

mediodorsally with ventral tegmental decussation, and fine granules in the ventrolateral part of red nucleus are laterally with the fine granules at its lateral outer area.

Plate III, 1 (A : 3.0) There is granular concentration in the mediodorsal part of red nucleus, and also its dorsal outer area, which are continuous with large granules scattered in medial longitudinal fascicle and with fine granules at the medioventral part of central gray and its outer extent. Oculomotor nucleus is free of granulation. Granular stream is found medial to red nucleus along the decussation of superior cerebellar peduncle dorsal to interpeduncular nucleus into the medial capsule of red nucleus of the opposite side. There is a stream of large granules at the area ventral to red nucleus which extends mediodorsally towards superior cerebellar peduncle and medial lemniscus, of which the latter appears intact. Fine granules are diffusely found in reticular formation laterodorsal to red nucleus.

Plate III, 2 (A : 2.0) Dense granular concentration of small and partly large calibres is distinctly seen ventrolateral to medial longitudinal fascicle. There are fine granules ventrolateral to central gray and also at reticular formation. Dorsal tegmental decussation and thc decussation of superior cerebellar peduncle are free of granulation at this level. Large granules are scattered in medial longitudinal fascicle.

Plate III, 3 (A : 1.0) Same as in A : 2.0.

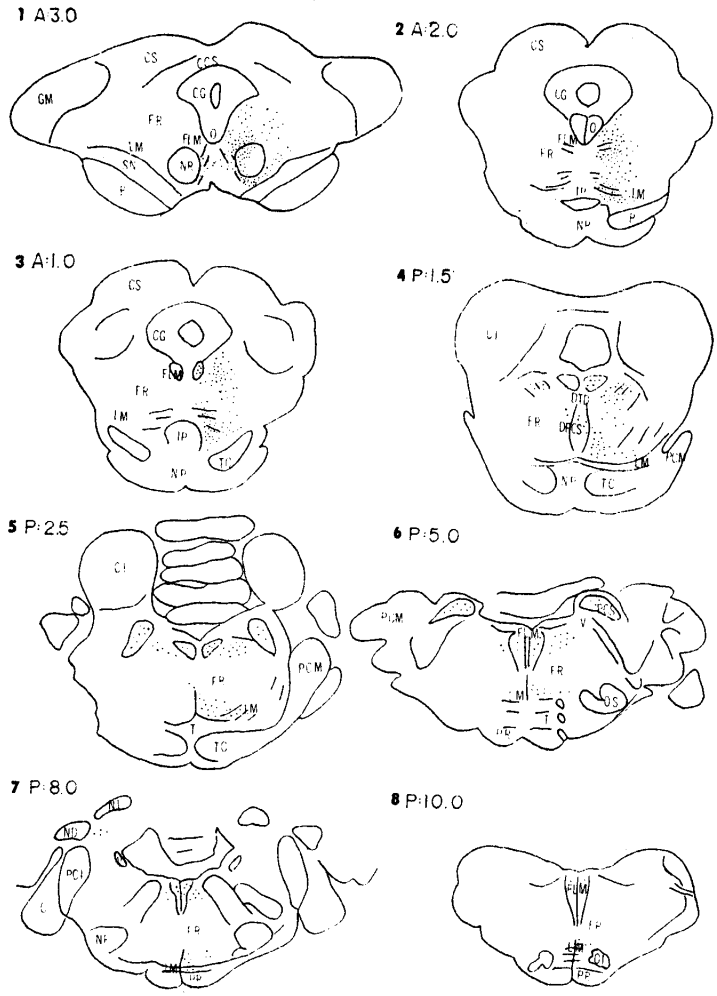
Plate III, 4 (P : 1.5) Both large and small granules are in the ventral and dorsal mesencephalic reticular formation. The latter is laterally continuous with the granules in superior cerebellar peduncle. *Medial lemniscus* and *N. reticularis tegmenti pontis* are covered with fine granules. Small granules cross the midline dorsolaterally through the decussation of superior cerebellar peduncle out of the ventral group. Denser granulation is observed in superior cerebellar peduncle of the opposite side in comparison with the oneo f the same side. *Medial longitudinal fascicle* remains to be ranulated. There are few granules in *N. reticularis pontts caudalis.*

Plate III, 5 (P : 2.5) Same as in P : 1.5. However, *N. reticularis pontis caudalis* is scarcely granulated, and medial longitudinal fascicle involves only small granules.

Plate III, 6 (P : 5.0) Fine granules are scattered both in the ventral and dorsal areas of reticular formation but the latter is more densely granulated. Medial longitudinal fascicle and superior cerebellar peduncle are granulated same as seen in the previous section.

Plate III, 7 (P : 8.0) Both sides of medial longitudinal fasciles are granulated, denser at the same side. There are also fine granules at the midlateral outer area of the bilateral fascicles. Granulation is seen at the medial border of the

Plate Ⅲ.



contralateral dentatus nucleus and at medial lemniscus and ventral reticular formation of the same side.

Plate III, 8 (P: 10.0) There are very few granules in bilateral medial longitudinal fascicles and ipsilateral medial lemniscus.

DISCUSSION AND SUMMARY

It is very important to differentiate the passage fibers and originating fibers for the anatomical analysis of the area such as the Forel H field which is consisted of cells and fibers. Subthalamus is predominantly a fiber field[28], and the field H of Forel should probably not be considered as a nuclear and functional entity[6,7]. It is, therefore, necessary to follow the centripetal or retrograde degeneration from the lesion of the H-field, which could tell the origination and termination of both types of the fibers, in correlation with the centrifugal degeneration study as seen in the Marchi method.

Subthalamus is generally believed to contain motor coordinating centers relaying impulses of cortical, striatal, and thalamic origin to lower centers[15] and stands in the domain of motor function and in relation to some of the imperative function of the muscular systems and is the internode through which the motor paths of the cerebellum and tegmental region are brought into relation with the corpus striatum[28].

Physiological study revealed that the lesion of bilateral Forel H-fields caused the threshold increment for eliciting corticogenic epileptic convulsion[22]. Anatomical study is expected for the functional mechanism because the parallel correlation could be existed between them.

FOREL[13] pointed out the passage fibers in the H-field come from the posterior longitudinal fascicle, reticular formation and brachium conjunctivum and/or red nucleus. One of the major fiber groups, H1 is kept in direct continuity with external medullary lamina to become the most dorsal aud most medial longitudinal fibres of the thalamus. Another major group, H2 has three branches; the first, the right angled transverse fibers into internal capsule at its border of pes peduncle, the second, a small fiber component into hypothalamus and tuber cinereum dorsal to the anterior radix of fornix, and the third, forming lenticular ansa at the medial end of internal capsule (*Substantia innominata Reil*).

BODIAN[6,7] noted that the H-field is the field of passage of many fibers, especially lenticular bundles (H1 and H2) and the cells in this area are probably connected with the lenticular bundle and ansa, and are also associated with zona incerta, posterior longitudinal fascicle and tegmentum. According to PAPEZ[28], the broad anteroposterior extent of the fields of H1 and H2 and their scattered cells provide large synaptic areas between the subthalamus and the striatum.

This study reveals that the fiber degeneration at the lesion of the Forel H-field is more extensive than the one in those reports. This might be interpreted by the fact of the reciprocal fiber connection from the field. And the fiber connection will be explained as in the following.

1) To cortex: The fiber connection to the ipsilateral anterior sigmoid gyrus exists through internal capsule mediodorsal to entopeduncular nucleus and, further anteriorly, to putamen and claustrum. This is the reciprocal pathway of the corticofugal through fibres reported by AUER[4], AKIBA[1] and KISHI[18] in cat brain.

2) To caudate nucleus: Through internal capsule to the ventrolateral part of the ipsilateral nucleus. There are, however, no reports describing the fiber connection from nucleus to H-field[26,34,36].

3) To putamen: There is fiber connection from H-field to putamen directly through internal capsule. This is based on the observation that the granule is decreased in number in its anterior course through internal capsule between the level of putamen and claustrum indicating the termination of some of them in the putamen. There is no evidence of the reciprocal fiber connection via globus pallidus, although there are several reports concerned with the putamofugal fibers to the lenticular ansa and fascicle through globus pallidus[12,19,25,36,37].

4) To globus pallidus: There are two connections; one via internal capusle (H2) and the other via entopeduncular nucleus and the medial edge of pes peduncli[13]. They are obviously reciprocal pathway of the lenticular fascicle and ansa[17,36,37].

5) To hypothalamus: There are fiber connections to the dorsomedial, posterior, lateral, ventromedial and filiformis nuclei[6,7,26].

6) To thalamus: There are connections to reticularis, ventroposteromedialis, ventroposterolateralis, centralis centralis, parafascicularis, ventralis lateralis, ventralis anterior and ventralis medialis nuclei of the thalamus. There are however, no connections to the nucleus medial to internal medullary lamina.

7) To cerebellum and brachium conjenctivum: There is a reciprocal pathway along the ascending interposed-dentate projection of the cerebellofugal fibers according to the reports by MCMASTERS and RUSSEL[21] and COHEN *et al*[11]. There are a number of investigations concerned with the ascending brachium projection through the H-field[2,9,10,24,27,29,33,35]. The findings of the degeneration of bilateral superior cerebellar peduncles suggest the existence of the reciprocal pathways of the bilateral ascending cerebellofugal projection noted by NIIMI *et al*[24]. RANSON and INGRAM[29] described that the ascending fibers of brachium conjunctivum are concentrated at the ventral, medial and dorsal capsules of red nucleus and also at the dorsomedial area to its anterior pole, and at the ventrolateral area to

oculomotor nucleus in the level just anterior to it in its anterior course. It is to be noted that the degeneration was of the same distribution pattern in the posterior course. The degeneration granules in the centralis centralis, ventralis lateralis, ventralis anterior and ventroposteromedialis nuclei of the thalamus would correspond to the interception of the ascending cerebellofugal fibers at the H-field (dentorubrothalamic fibers).

8) To red nucleus: There is a dense fiber connection to the ipsilateral red nucleus, especially to its mediodorsal part, and also to the contralateral nucleus through tegmental decussation. CARPENTER[8], and HINMAN and CARPENTER[14] described that the ascending rubrofugal fibers run into ventralis lateralis, ventroposteromedialis, ventroposterolateralis and ventralis medialis through H1, and into subthalamic nucleus, globus pallidus (internal segment), parafascicularis, centralis centralis and reticularis nuclei through H2. The degenerated granular distribution in this study suggests that these ascending projections are intercepted at the H-field.

9) To medial lemniscus: The connection was observed down to the level of P: 10.0, and appears to be the reciprocal pathway of the lemniscal fibers as reported by ALLEN[2], MATZKE[20] and BOWSHER[5].

10) To spinothalamic tract: Although NAUTA *et al.*[23] and ANDERSON and BERRY[3] noted a part of the tract has connection to the H-field, no fiber connection could be found from the H-field in this study.

11) To reticular formation: There are connections to mesencephalic and pontine reticular formation down to the level rostral to the inferior olive. This is believed to be the reciprocal pathways of the ascending Forel's tractus fasciculorum tegmenti (NAUTA and KUYPERS[23]). It is interesting to note that the degeneration has the same distribution as their finding of the tractus being concentrated at the area ventrolateral to medial longitudinal fascicle and abruptly separated into the thalamic and subthalamic components at the level rostral to the red nucleus.

12) To others: There is a firm connection via lenticular ansa to globus pallidus of the opposite side through supraoptic commissure (MEYNERT or GUDDEN), though no reports could be found dealing with this connection, and also bilaterally into medial longitudinal fascicles and their ventral nuclear group[6,7,13]. There are connections with zona incerta, subthalamic nucleus and substantia nigra, positively bilaterally, as well as with the Forel H-field of the opposite side in spite of the impossibility of determination of the terminal connection in this experimental method. Fiber connection exists to the ipsilateral central gray, interstitial nucleus and nucleus of the posterior commissure.

CONCLUSION

An anatomical study was made to follow the degeneration of fibers by means of Marchi technique in cat after making experimentally lesion in Forel H field. As the results the following conclusions were reached.

1) The ipsilateral distribution of the degenerated granules was in the anterior sigmoid gyrus, caudate nucleus, putamen and globus pallidus, thalamic nuclei medial to the internal medullary lamina, substantia nigra, rubrocerebellar system, medial longitudinal fascicle system, mesencephalic and pontine reticular formation and medial lemniscus.

2) There was also contralateral distribution to the interpositus and dentatus nuclei of the cerebellum via brachium conjunctivum, to globus pallidus via supraoptic commissure, to subthalamic region and substantia nigra via supramammilary commissure, and to red nucleus via tegmental decussaion.

3) The degeneration is so extensive that the Forel H-field seems to be the cross road of the extrapyramidal system in association with brainstem activating system.

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Abbreviations for Nomenclature

C: N. cochlearis
CA: Commissura anterior
CCS: Commissura colliculi superioris
CI: Colliculus inferior
CIN: Capsula interna
CG: Substantia grisea centralis
CL: Claustrum
CM: Centrum medianum (N. centralis centralis)
CP: Commissura posterior
CS: Colliculus superior
D: N. Darkschewitsch
DF: Decussatio Foreli supra-mamillaris
DPCS: Decussatio peduncul. cerebell. superiorum
DTD: Decussatio tegmenti dorsalis
DTV: Decussatio tegmenti ventralis
E: N. entopeduncularis
FLM: Fasciculus longitudinalis medialis
FR: Formatio reticularis
FX: Corpus et Columna fornicis
GL: Corpus geniculatum laterale
GM: Corpus geniculatum mediale
GP: Globus pallidus
H: N. habenulae
HA: Area hypothalami anterior
HD: N. hypothalami dorsalis
HI: Tractus habenulo-interpeduncularis
HL: N. hypothalami lateralis
HP: Area hypothalami posterior
HVM: N. hypothalami ventromedialis
I: N. interstitialis
IP: N. interpeduncularis
LM: Lemniscus medialis
M: Corpus mamillare
MD: N. medialis dorsalis
NC: N. caudatus
NCM: N. centralis medialis
NCP: N. commissurae posterioris
ND: N. dentatus
NF: N. n. facialis
NI: N. interpositus
NP: N. pontis
NR: N. ruber
O: N. n. oculomotorii
OI: N. olivaris inferior
OS: N. olivaris superior
P: Pedunculus cerebri
PCI: Pedunculus cerebellaris inferior
PCM: Pedunculus cerebellaris medius
PCS: Pedunculus cerebellaris superior
PF: N. parafascicularis
PR: Tractus pyramidalis
PT: Putamen
R: N. reticularis
S: N. subthalamicus
SN: Substantia nigra
T: Corpus trapezoideum
TC: Tractus corticospinalis et corticobulbaris
TO: Tractus opticus
V: N. vestibularis
VA: N. ventralis anterior
VL: N. ventralis lateralis
VM: N. ventralis medialis
VPM: N. ventralis posteromedialis