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Anatomical Studies on Conduction Pathways of Advcrsive Movement

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Abstract

1. The descending fi bers from the areas 8 and 6 aβ reaching the lateral and ventral nuclei of the homolateral thalamus are recognized. They are considered to be the conduction pathways of the adversive movements caused by the stimulations on the areas 8 and 6 aβ. 2. The descending fibers from the areas 5, 7, 19 and 22 reaching the head and the tail of the homolateral caudate nucleus are revealed. These fibers are considered to be the conduction pathways of the adversive movement caused by the stimulation on these areas. Moreover, the descending fibers from the areas 7, 19 and 22 reaching the homolateral superior colliculus are recognized. These fibers are also considered to participate in the adversive movement. 3. The fibers from the lateral and ventral nuclei of the thalamus reaching the homolateral superior colliculus, Cajal's interstitial nucleus and reticular formation of the mesencephalon are observed. These fibers are considered to be the conduction pathways of the adversive movement from the thalamus. 4. The caudate nucleus and the lenticular nucleus are connected closely by the numerous fiber bundles croing the internal capsule. 5. The fibers from the lenticular nucleus which participate in the adversive movements descend through the lenticular fasciculus, Forel's field, the comb-fibers in the cerebral peduncle, substantia nigra and medial lemniscus, and then reach the stratum lemnisci et profundum of the homolateral superior colliculus, Cajal's interstitial nucleus, Darkschewitsch's nucleus, Westphal-Edinger's nucleus, oculomotor nucleus and trochlear nucleus. 6. The tectobulbar tracts from the superior colliculus joined with the both oculomotors, contralateral trochlear, abducens, facial and acceory nuclei, thus they are considered to take part in the adversive movement. 7. The ascending fibers from the dentate nucleus pa through the homolateral brachium conjunctivum and reach the contralateral trochlear and oculomotor nuclei, superior colliculus and the lateral and ventral nuclei of the contralateral thalamus. These ascending fibers are considered to be the conduction pathways of the adversive movement from the cerebellum.

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ANATOMICAL STUDIES ON CONDUCTION PATHWAYS OF ADVERSIVE MOVEMENT

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It is well known that adversive movement, such as the turning of eyes, head and neck, sometimes even the upper part of body to one side, can usually be seen in an epileptic seizure. The turning side of adversive movement is being thought to be the side opposite to the cerebral cortex with the epileptic focus. These facts have been proved by KAWAMATA[1] who observed the convulsions of epileptic patients provocated by injecting metrazol. He has reported that the adversive movements invariably tended to turn to the side opposite to the cerebral cortex with the pathological changes in the cases of symptomatic epileptics. OGAWA[2], one of our co-workers, found also the same in his experiments with dogs. He provocated the convulsion in dogs after making the difference of excitability between both cerebral hemispheres by either giving the stimulating below threshold or application of novocaine on one side. He then recognized an adversive movement, the turning of head to the side opposite to the excited cerebral cortex. Thus, the adversive movement is considered to occur when there exists a difference in the degree of excitability between both cerebral hemispheres. On the other hand, it has been reported by many authors since FRITSCH and HITZIG[3] (1870) that adversive movements are observed by stimulating various parts of the cerebral cortex.

C. and O. VOGT[4] observed adversive movement by the electrical stimulation on the cerebral cortex of apes, and classified cortex areas as follows: areas, producing adversive movement by weak stimuli, were 6 a β, 8 α, 19 a, and 22 a; those, by moderate stimuli, were 8 β, 9, 10, 7 b, and 5 b; and those by strong stimuli were 8 δ, 4 a, 4 b, 4 c, 3 a, 3 b, 1, 2, and 7 a. FOERSTER[5] described the areas of adversive movement on human brain by electrical stimulations as follows: the area 6 a β as frontal adversive field, the areas 8 α, 8 β and 8 δ as frontal eye field the areas 5 and 7 as parietal adversive field, the area 19 as occipital eye field, and the area 22 as temporal adversive field. They thought that the adversive movement was induced by the efferent fibers from each area; but details of them were unknown. HIRASAWA[6] studied the extrapyramidal systems of the cerebral cortex extensively, but he could not give clear explanation about conduction pathways of the adversive movement. He imagined, however, that the extrapyramidal corticofugal fibers reaching the caudate nucleus, globus pallidus, thalamus, substantia nigra, stratum intermedium pedunculi, Forel's field and red nucleus would take part in the adversive movement.

Recently, OGAWA[2] and KOSAKA[7] investigated physiologically the origins and conduction pathways of the adversive movement in dogs, and concluded as follows: from the areas 6 a β, 8, 4 c, 5, 7, 19, and 22 of the cerebral cortex of dog, which were classified by KLEMPIN[8] as such, adversive movement was induced by the electrical and metrazol stimulations and they clarified three groups of the conduction pathways. The first group arises from the areas 8 and 6 a β, and, passes through the thalamus of the same side and the second from the areas 5, 7, 19 and 22, and, passes through the caudate nucleus and lenticular nucleus of the same side. The both groups run downward in the cerebral hemisphere of the same side and reach homolateral superior colliculus or its vicinity in the tegmentum of the mesencephalon, from there they cross to the opposite side and reach the nuclei of motor cranial nerves: abducens, facialis, accessorius, and so on. The third group from the area 4 c passes through internal capsule and ends straight to these contralateral nuclei of motor cranial nerves after crossing. Another conduction pathway of adversive movement from the cerebellar cortex passes through the homolateral dentate nucleus and brachium conjunctivum and reaches the tegmentum of the midbrain and the thalamus on the opposite side, where it connects with the pathways from the cerebral cortex.

We intended to prove anatomically these conduction pathways of adversive movement, which had been clarified physiologically by OGAWA[2] and KOSAKA[7].

METHODS OF EXPERIMENTS

Using dogs as experimental animals, small lesions with incision or electrical coagulation were made on the cerebral cortex (areas 8, 6 aβ, 5, 7, 19 and 22), and in the thalamus, caudate nucleus, lenticular nucleus, superior colliculus and dentate nucleus of cerebellum, in which the adversive movements by stimulation had been recognized. Killing dogs by the bleeding of the carotid artery two weeks after these procedures, and removing the brains, serial sections were made by Marchi staining method. Again, the brain was removed five to seven days after the same procedure as stated above, and the serial sections were made by the Nautag staining method. Then the secondary degenerations of fibers were traced in these series of the sections.

RESULTS OF EXPERIMENTS

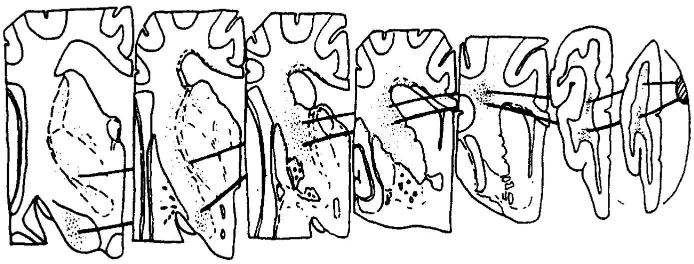
I. The conduction pathways from the adversive fields on the cerebral cortex.

1. The conduction pathways from the area 8.

Lesion (2 mm. square, 2 mm. deep) was made on the area 8 a, at the extreme anterior part of the lobus olfactorius.

Degenerations: Markedly degenerated granules were seen at the central and lower parts of the white matter in the frontal lobe (Fig. 1, 1 & 2 2), pes coronae radiatae (Fig. 1, 3), internal capsule (Fig. 1, 4 & 5) and cerebral peduncle (Fig. 1, 7) on the same side. Fine, degenerated granules were seen in the stratum subcallosum, stratum zonale nuclei caudati, the reticular, anterior, medial, lateral and ventral nuclei of the thalamus, upper part of the putamen and globus pallidus. Among these nuclei, there were considerably many degenerated granules in the lateral and ventral nuclei of the thalmus.

Fig. 1 Secondary degenerations from the area 8.



The corticofugal projection fibers from the area 8 proceed backward in the white matter of the frontal lobe, enter the pes coronae radiatae at the level of the caput nuclei caudati, and pass gradually downwards in the internal capsule and then reach the central part of the cerebral peduncle. On their way through this route, these fibers connect with the caudate nucleus, reticular, anterior, medial, lateral and ventral nuclei of the thalamus, the putamen and the globus pallidus.

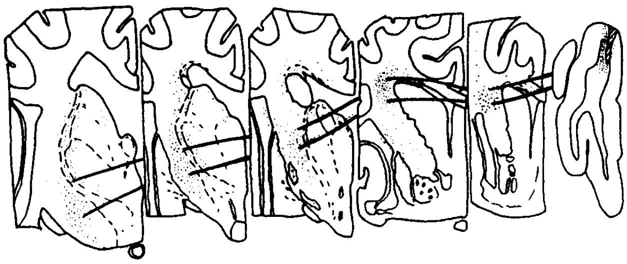
It has been proved that there were fibres terminating in the nuclei of the thalamus from the area 8, and of these, many reach mainly the lateral and ventral nuclei of the thalamus.

2. The conduction pathway from the area 6 a$_\beta$.

Lesion (2 mm. square, 2 mm. deep) was made on the area 6 a$_\beta$, posterior part of the gyrus proreus.

Degenerations: Remarkable, degenerated granules were recognized in the upper part of the corona radiata of the gyrus proreus (Fig. 2, 1), centrum semiovale (Fig. 2, 2) and upper part of the anterior limb of the internal capsule (Fig. 2, 3), and scattered granules in the posterior limb of the internal capsule (Fig. 2, 4 & 5,) and the middle part of the cerebral peduncle (Fig. 2, 6). Fine, degenerated granules were seen in the stratum subcallosum, stratum zonale nuclei caudati, caudate nucleus, the

Fig. 2 Secondary degenerations from the area 6 a β.



reticular, anterior, medial, lateral and ventral nuclei of the thalamus, Forel's field, upper part of the claustrum, putamen and globus pallidus. In the lateral and ventral nuclei of the thalamus, considerably many degenerated granules were recognized.

The corticofugal projection fibers from the area 6 a$_\beta$ run backward through the upper part of the corona radiata of the gyrus proreus, passing through the centrum semiovale and upper part of the anterior limb of the internal capsule at the level of head of the caudate nucleus, diverge in the genu of the internal capsule through the central part of it, close to the thalamus and gradually descend through the frontopontile tract in the cerebral peduncle. Passing through the internal capsule, these fibers connect with the caudate nucleus, the reticular, anterior, medial, lateral and ventral nuclei of the thalamus, Forel's field, the claustrum, the putamen and the globus pallidus.

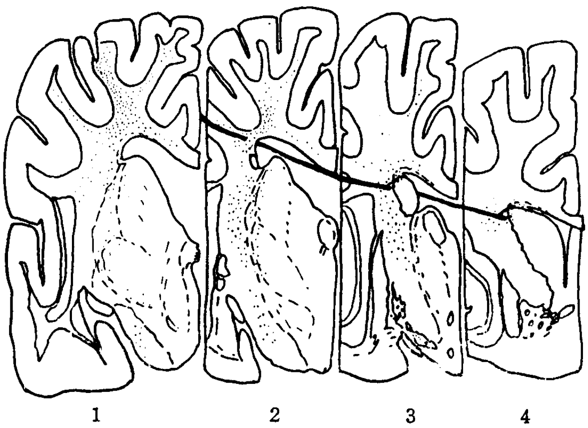
Among these nuclei, a greater number of degenerated granules were found in the lateral and ventral nuclei of the thalamus. This seems to suggest that the projection fibers from the area 6 a$_\beta$ to the lateral and ventral nuclei of the thalamus are stronger.

3. The conduction pathways from the area 5.

Lesion (2 mm. square, 2 mm. deep) was made on the area 5 b, anterior part of the gyrus ectolateralis.

Degenerations: Markedly degenerated granules were revealed in the corona radiata of the gyrus ectolateralis (Fig. 3, 1), centrum semiovale, the middle and lower parts of the internal capsule (Fig. 3, 2) and scatteringly in the middle part of the internal capsule (Fig. 3, 3). Fine, degenerated granules were recognized scatteringly in the lower part of the centrum semiovale, stratum subcallosum, stratum zonale nuclei caudati, the anterior part of the tail and the posterior and middle parts of the head of the caudate nucleus, the reticular, lateral and ventral nuclei of the thalamus, pulvinar thalami and medial and lateral geniculate bodies.

Fig. 3 Secondary degenerations from the area 5.



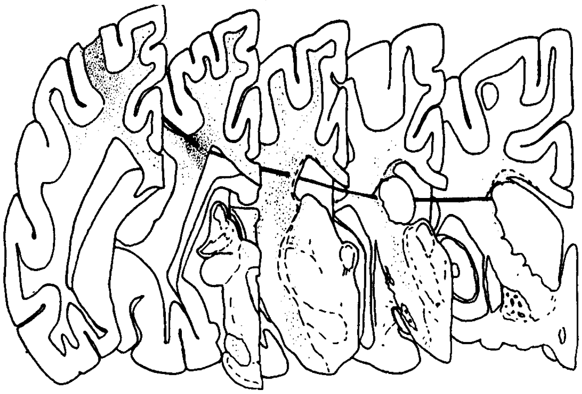
The corticofugal projection fibers reaching the caudate nucleus from the area 5 descend through the corona radiata of the gyrus ectolateralis, proceed forward in the centrum semiovale scatteringly and reach the anterior part of the tail and the posterior and middle parts of the head of the caudate nucleus through the stratum subcallosum and stratum zonale nuclei caudati, and partly through the internal capsule.

4. The conduction pathways from the area 7.

Lesion (2 mm. square, 2 mm. deep) was made on the area 7 b, middle part of the gyrus lateralis.

Degenerations: Remarkable, degenerated granules were recognized in the corona radiata of the gyrus lateralis (Fig. 4, 1), upper central part of the centrum semiovale (Fig. 4, 2), scatteringly in the pes coronae radiatae and cerebral peduncle (Fig. 4, 3) and in the middle part of the internal capsule (Fig. 4, 4). Fine, degenerated granules were recognized in the stratum subcallosum, stratum zonale nuclei caudati, the anterior part of the tail and the posterior part of the head of the caudate nucleus, the reticular, lateral, ventral and anterior nuclei of the thalamus, pulvinar thalami, laernal geniculate body, claustrum, putamen, globus pallidus, superior colliculus, substantia nigra and pontile nuclei.

Fig. 4 Secondary degenerations from the area 7.



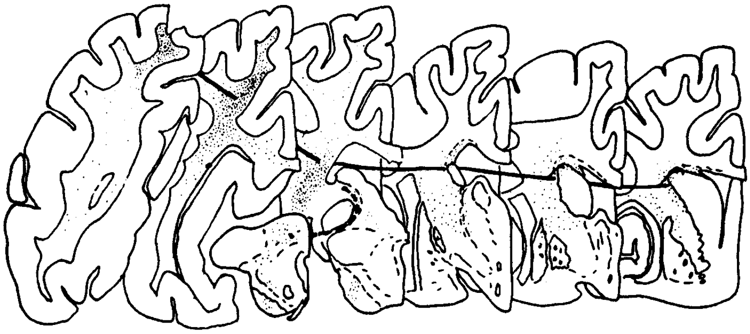
The corticofugal projection fibers reaching the caudate nucleus from the area 7 descend through the corona radiata of the gyrus lateralis, extend forward in the centrum semiovale scatteringly and terminate in the anterior part of the tail and the posterior part of the head of the caudate nucleus through the stratum subcallosum, stratum zonale nuclei caudati and internal capsule.

5. The conduction pathways from the area 19.

Lesion (2 mm. square, 2 mm. deep) was made in the area 19, posterior part of the gyrus suprasplenialis.

Degenerations: Markedly degenerated granules were recognized in the corona radiata of the gyrus suprasplenialis, the upper part of the centrum semiovale (Fig. 5, 1 & 2), the central part of the centrum semiovale and partly in the cerebral peduncle (Fig. 5, 3) and scatteringly in the upper part of the internal capsule (Fig. 5, 4 & 5). Fine, degenerated granules were revealed in the pes coronae radiatae, the upper part of the internal capsule, the stratum subcallosum, stratum zonale nuclei caudati, the tail and head of the caudate nucleus, the reticular, lateral, ventral and anterior nuclei of the thalamus, pulvinar thalami, lateral geniculate body, claustrum, putamen, globus pallidus, superior colliculus, substantia nigra and pontile nuclei.

Fig. 5 Secondary degenerations from the area 19.



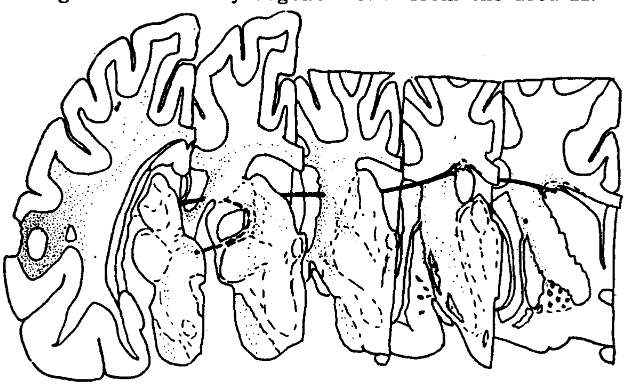
The corticofugal projection fibers from the area 19 descend forward in the corona radiata of the gyrus suprasplenialis, centrum semiovale and pes coronae radiatae. Some fibers of them terminate in the tail and the head of the caudate nucleus through the stratum subcallosum, stratum zonale nuclei caudati and internal capsule.

6. The conduction pathways from the area 22.

Lesion (2 mm. square, 2 mm. deep) was made in the area 22, upper part of the gyrus ectosylvius posterior.

Degenerations: Markedly degenerated granules were observed in the corona radiata of the gyrus ectosylvius posterior (Fig. 6, 1), the part close to the claustrum in the centrum semiovale (Fig. 6, 2 & 3) and partly in the stratum reticularis of the thalamus and the cerebral peduncle (Fig. 6, 3), and scatteringly granules in the upper part of the internal capsule

Fig. 6 Secondary degenerations from the area 22.



near by the claustrum and putamen (Fig. 6, 4). Fine, degenerated granules were recognized in the claustrum, putamen, globus pallidus, stratum subcallosum, stratum zonale nuclei caudati, the tail and the head of the caudate nucleus, the reticular, lateral, ventral and anterior nuclei of the thalamus, pulvinar thalami, medial and lateral geniculate bodies, superior colliculus and substantia nigra.

The corticofugal projection fibers from the area 22 pass through the corona radiata of gyrus ectosylvius posterior and centrum semioval close to the medial side of the claustrum. Some of them terminate in the tail and the head of the caudate nucleus through the stratum subcallosum, stratum zonale nuclei caudati and internal capsule.

II. The conduction pathways from the thalamus.

By the metrazol stimulation of the middle nuclear group (medial, lateral and ventral nuclei) and posterior nucleus of the thalamus, Ogawa recognized the adversive movement but after the removal of these nuclei, adversive movement could not be seen by the stimulation on the areas 8 and 6 aβ. These facts indicate that there are the synapses of the conduction pathways of the adversive movement from the areas 8 and 6 aβ in the middle and posterior nuclei of the thalamus, and they connect with the second neurons from these nuclei of the thalamus. Moreover, further studies proved physiologically that the second neurons from these nuclei of the thalamus reached the homolateral superior colliculus and its vicinities.

The insulated needle with the 1.5 mm. length of naked tip was inserted from the posterior part of the gyrus ectolateralis and small electrically coagulated lesion was made in the posterior part of the reticular and lateral nuclei and the lateral part of the ventral nucleus of the thalamus (Fig. 7 & 8).

Degenerations: The degenerated granules were recognized rather strikingly in the surroundings of the lesion in the ventral nucleus and lateral medullary lamina, while the small degenerated granules were less in the lateral nucleus (Fig. 7). The considerably many fine, degenerated granules were recognized in the surroundings of the lesion, the upper part of the ventral nucleus and lateral medullary lamina, and partly in the lateral geniculate body, and a few fine, degenerated granules were scatteringly in the medial nucleus, pulvinar thalami, Forel's field, Luys's body and partly tuber cinereum (Fig. 8). In the section at the anterior part of the superior colliculus, a considerable number of remarkably degenerated granules were recognized in the posterior lower part of the ventral nucleus, the stratum lemnisci and profundum of the superior colliculus and Forel's field, a few in the Luys's body and Cajal's interstitial nucleus

Fig. 7 Coagulated losion in the ventral nucleus of the thalamus

Fig. 8 Coagulated losion in the ventral nucleus of the thalamus

Fig. 9 Secondary degenerations from the lateral and ventral nucleus of the thalamus (section at the porteria commissure).

Fig. 10 Secondary degenerations from the lateral and ventral nucleus of the thalamus (section at the soperior colliculus).

(Fig. 9). In the section at the middle part of the superior colliculus, rather many degenerated granules were seen in the superior colliculus and the medial lemniscus, and a few in the medial geniculate body and dorsal part of the red nucleus (Fig. 10).

The descending fibers from the lateral and ventral nuclei of the thalamus pass backward through the upper part of the ventral nucleus of the thalamus and the anterior part of the medial geniculate body and reach the medial lemniscus. From there, two groups of the fibers reach the superior colliculus, one of them to the stratum opticum and the other to the stratum lemnisci et profundum; furthermore, the latter passes through the radiatio tegmenti, Forel's field and ventral part of the tegmentum mesencephali and connects with Luys's body, Cajal's interstitial nucleus, red nucleus and its near part and reticular formation. These fibers are considered to participate in the adversive movement from the thalamus.

The electrically coagulated lesion was made mainly in the medial nucleus of the thalamus but the descending degenerated fibers from there to the midbrain could not be recognized.

III. The conduction pathways from the caudate nucleus and the lenticular nucleus.

OGAWA[2] observed adversive movement clearly by the metrazol stimulation of the caudate nucleus and lenticular nucleus. After removal of these nuclei, the adversive movement could no longer be seen by stimulations of the areas 5, 7, 19 and 22. Then he reported that the first neurons of the conduction pathways of adversive movement from the areas 5, 7, 19 and 22 changed to the second neurons at the caudate nucleus, relayed to the third neurons at the lenticular nucleus and these third neurons in turn terminated in the homolateral superior colliculus and its vicinities of the tegmentum of the mesencephalon.

A small electrically coagulated lesion was made in the upper part of the head of the caudate nucleus (Fig. 11).

Degenerations: The degenerated granules were recognized in the bundles of small fibers around the lesion and the middle part of the caudate nucleus and in many bundles crossing the internal capsule. Fine, degenerated granules were seen quite abundantly in the surroundings of the lesion (Fig. 11). Directly behind the lesion, the degenerated granules were recognized in many bundles in the caudate nucleus and internal capsule, and in the putamen and globus pallidus (Fig. 12).

The degenerated fibers from the lesion in the head of the caudate

Fig. 11 Lesion in the caudate nucleus.

Fig. 12 Secondary degenerations from the caudate nucleus.

nucleus pass through the numerous bundles which cross the internal capsule and reach to the lenticular nucleus. The degenerated fibers from the middle part of the head of the caudate nucleus reach the middle part of the lenticular nucleus, so that the connection between the caudate nucleus and the lenticular nucleus has a certain intercommunication in their arrangement.

A small coagulated lesion was electrically made in the lower part of the putamen and in the middle part of the globus pallidus (Fig. 13).

Degenerations: In the section at the middle part of the lenticular nucleus and the anterior part of the thalamus, the degenerated granules were seen in the surroundings of the lesion and particularly in the internal capsule. A few degenerated granules were found in the small bundles reaching the medial nucleus of the thalamus (Fig. 13). In the section at the posterior part of the putamen and the thalamus, considerably many small degenerated granules were recognized in the lateral lower part of the internal

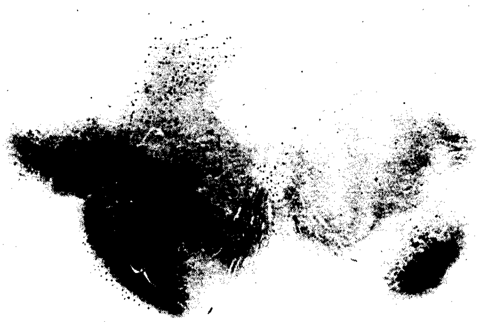
Fig. 13 Lesion in the leuticular nucleus.

Fig. 14 Secondary degenerations from the lenticular nucleus (section at the posterior part of the putamen).

capsule, Forel's field, fasciculus lenticularis, the crossing comb fibers in the cerebral peduncle, Luys's body and reticular, lateral and ventral nuclei of the thalamus, but a few in the lateral part of the mammilloinfundibular nucleus and Forel's field on the opposite side (Fig. 14). In the section at the posterior commissure, considerably many degenerated granules were recognized in the medial ventral part of the medial geniculate body, medial lemniscus, pretectal region, cerebral peduncle, substantia nigra and red nucleus, a few in the Darkschewitsch's nucleus and Cajal s interstitial nucleus (Fig. 15). In the section at the middle part of the superior colliculus, considerably many degenerated granules were observed in the stratum lemnisci et profundum of the superior colliculus, medial lemniscus, substantia nigra, red nucleus oculomotor nucleus on the same side; but a few in the superior colliculus, red nucleus and oculomotor nucleus on the opposite side (Fig. 16).

Fig. 15 Secondary degenerations from the lenticular nucleus (section at the posterior commissure).

Fig. 16 Secondary degenerations from the lenticnlar nucleus (section at the supesion colliculus).



The efferent descending fibers from the lenticular nucleus pass by the upper border of the posterior part of the globus pallidus and the putamen, and enter the bottom of the cerebral peduncle, then cross it upwards as scattered comb fibers, the minority of them connect with the Luys's body, zona incerta and mammilloinfundibullar nucleus while the majority of them pass through the lenticular fasciculus and Forel's field connecting with the ventral nucleus of the thalamus. At the posterior part of the diencephalon these fibers pass through the medial lemniscus and the minority of them reach the pretectal region and stratum lemnisci and profundum of the superior colliculus.

A part of the efferent descending fibers from the lenticular nucleus pass through the cerebral peduncle and connect with the substantia nigra in its lateral and middle part. Furthermore, the minority of them through the substantia nigra and medial lemniscus reaches the red nucleus and lesser part of them through the medial longitudinal fasciculus and connect with the Cajal's interstitial nucleus, Darkschewitsch's nucleus, Westphal-Edinger's nucleus and oculomotor nucleus; and a few of them pass through reticular formation of the mesencephalon and connect with the homolateral trochlear nucleus.

IV. The conduction pathways from the superior colliculus.

OGAWA[2] reported that the parts where the adversive movement was observed by the metrazol stimulation in the mesencephalon were the superior colliculus, oculomotor nucleus and its adjacent part. And the descending fibers conducting adversive movement from the superior colliculus and its vicinity of the tegmentum crossed to the opposite side and connected with the nuclei of the motor cranial nerves in the brain stem.

It is well known that there are the tectobulbar and tectospinal tracts as the decending fibers from the superior colliculus. PAPEZ and FREEMAN[9], and TSAI[10] reported that there were some connections between these tracts and nuclei of the motor cranial nerves in the brain stem, while TASHIRO[11] found no connection.

The superior colliculus of one side was removed almost completely.

Degenerations: At the anterior part of the superior colliculus a considerable number of remarkable, degenerated granules were recognized in the bottom of the lesion, central gray matter, medial geniculate body, both red nucleus and Westphal-Edinger's nucleus. Marked, degenerated granules were observed in the bundles running by the central gray matter. In the middle part of the superior colliculus and red nucleus, remarkably degenerated granules were recognized in many bundles running by the central gray matter and oculomotor nucleus. These degenerated bundles crossed at the ventral part of the oculomotor nucleus. Degenerated granules were seen in the basal part of the lesion, considerably many in the oculomotor nucleus, red nucleus and reticular formation on the both sides a few in the substantia nigra (Fig. 17). In the middle part of the inferior colliculus, degenerated granules were observed remarkably in the predorsal fasciculus of the opposite side, considerably many in the predorsal fasciculus on the side of lesion, inferior colliculus and lateral and medial lemniscus of the homolateral side, not so many in the trochlear nucleus and reticular formation, a few in the pontile nuclei (Fig. 18). At the rostral part of the medulla oblongata, a considerable number of degenerated granules were seen in the predorsal fasciculus, abducens nucleus, vestibular nucleus on the opposite side, and in the reticular formation on the side of the lesion (Fig. 19). In the middle part of the medulla oblongata, degenerated granules on the predorsal fasciculus were less in number. There were a few degenerated granules in the bottom of the fourth ventricle and nuclei of the amibguus, accessorius, hypoglossus and ala cinerea.

Fig. 17 Lesion in the superior colliculus.

Fig. 18 Secondary degenerations from the superior colliculus (section at the infesion colliculus).

In the descending fibers from the superior colliculus, the most degenerated fibers were found in the fasciculus praedorsalis *i. e.* in the tectobulbar and tectospinal tracts. The predorsal fasciculus descends close to the lateral

Fig. 19 Secondary degenerations from the inferior colliculus (section at the rostral part of the medulla oblonga).

part of the central gray matter and crosses to the opposite side at the ventral part of the oculomotor nucleus, then passes downward in the ventral part of the medial longitudinal fasciculus by the central rhaphe. In the predorsal fasciculus at the midbrain many degenerated granules were recognized, but in the middle of the medulla oblongata the number of the degenerated granules in the predorsal fasciculus decreased. This fact seems to suggest that predorsal fasciculus sends many connecting fibers into the mesencephalon, pons and rostral part of the medulla oblongata. The predorsal fasciculus connects with the Westphal-Edinger's nucleus before the decussation, with the oculomotor nucleus at the decussation, with the trochlear and abducens nuclei after the decussation; furthermore, with the facial and vestibular nuclei through the arcuate fibers. Moreover, it is considered that the nucleus alae griseum, ambiguus, accessori and hypoglossi, all have interconnections.

V. The conduction pathways from the dentate nucleus in the cerebellum.

OGAWA[2] reported that the conduction pathways of the adversive movement which had been also observed by the stimulation of the cerebellar cortex, originated from the lobus lunatus inferior, lobus semilunaris superior et inferior and lobus cuneiformis. The first neurons from these cerebellar lobes relayed to the second neurons at the homolateral dentate nucleus. The ascending second neurons from the dentate nucleus passed upward through the homolateral brachium conjunctivum and reached the tegmentum and the thalamus on the opposite side, then connected with descending pathways of the adversive movement from the cerebral cortex.

A small coagulated lesion was made electrically in the dentate nucleus and small part of the nucleus interpositus.

Degenerations: At the anterior part of the cerebellum, the coagulated lesion was seen in the upper part of the dentate nucleus. Markedly degenerated granules were seen in the surroundings of the lesion and the lateral and medial ventral parts of the corpus medullae of the cerebellum and fine, degenerated granules were in the vestibular nucleus (Fig. 20). Remarkable, degenerated granules were recognized in the decussatio brachium conjunctivum, fine, degenerated granules were a few in the trochlear nucleus, mainly on the opposite side, in the pontile nuclei, both inferior colliculi and the reticular formation of the tegmentum (Fig. 21). In the middle part of the superior colliculus and oculomotor nucleus, markedly degenerated granules were observed in the red nucleus and its dorsal part on the opposite side, a few mainly in the oculomotor nucleus, central gray matter, stratum profoundum of the superior colliculus and

Fig. 20 Lesion in the dentate nucleus.

reticular formation on the opposite side (Fig. 22). At the pretectal region remarkable degenerated granules were recognized in the dorsal part of the red nucleus on the opposite side and a few in the central gray matter, Westphal-Edinger's nucleus and upper medial part of the reticular formation on the opposite side. At the posterior commissure considerably many degenerated granules were revealed in the medial ventral part of the reticular formation and medial lemniscus, mainly on the opposite side and a few in the periventricular gray matter, Darkschewitsch's nucleus and Cajal's interstitial nucleus (Fig. 23). At the posterior part of the thalamus, slightly more degenerated granules were recognized in the Forel's field, ventral nucleus of the thalamus and a few in the medial and lateral nucleus of the thalamus on the opposite side.

Fig. 21 Secondary degenerations from the dentate nucleus (Section at the decussatio brachium conjunctivum).

Fig. 22 Secondary degenerations from the dentate nucleus (section at the superior colliculus).

The ascending fibers from the dentate nucleus gather gradually in the frontoventral part of the cerebellum and pass through the brachium conjunctivum, decussatio brachium conjunctivum, then enter the opposite side and pass through the red nucleus, the medial part of the reticular formation and Forel's field, then the majority of them reach the ventral and lateral nucleus of the thalamus on the opposite side and the minority in the medial nucleus of the thalamus on the opposite side. On their way, these fibers connect with the trochlear nucleus, red nucleus, oculomotor nucleus, Westphal-Edinger's nucleus, Darkschewitsch's nucleus, Cajal's interstitial nucleus, stratum profundum of the superior colliculus, pretectal region and the central and periventricular gray matter.

Fig. 23 Secondary degenerations from the dentate nucleus (section at the pretectal region).

DISCUSSION

The definition of the adversive movement differs somewhat among the scholars, but the definition that it is a contraversive deviation of the eyeballs, head, neck and upper body by the stimulation of the cerebral cortex is generally accepted.

As the conjugate deviation of the eyeballs was observed by the stimulation of the area 8, FOERSTER[5] named this area the frontal eye field. VOGT[4] and FOERSTER[5] thought that this ocular movement was conducted by the corticofugal extrapyramidal fibers from this area 8. On the other hand, RILEY[12] described that this area was the represntation of the ocular movement, and the pyramidal fibers from the Betz's cells in this area reached the oculomotor nucleus. At present, however, there are no definite evidences to prove these fibers anatomically as such. Although HIRASAWA and KATO[13] observed secondary degenerated fibers which seemed to reach the oculomotor nucleus etc. from the areas 8 and 9, this was also not clear. In our studies the secondary degenerated fibers from this area could not be recognized in the oculomotor, trochlear and abducens nuclei, but many fibers reaching the thalamus from the area 8 were demonstrated as OGAWA[2] pointed out physiologically. The secondary degenerated fibers were recognized in the reticular, anterior, lateral, ventral, and medial nuclei of the thalamus, particulary more in the lateral and ventral nuclei. These fibers are considered to participate in the adversive movement from the area 8.

Area 6 aβ was named the frontal adversive field by FOERSTER[5]. Many scholars thought that the adversive movement caused by the stimulation of the area 6 aβ was conducted by the efferent extrapyramidal fibers from this cortex because, even after cutting the association fibers, they could cause the adversive movement by the stimulation of this area.

HIRASAWA[6, 14] and his co-workers reported that efferent fibers from this area seemed to reach the oculomotor nucleus. But it was not definitive. After the removal of the small part which was the most dominant place to cause the adversive movement in the area 6 aβ, many degenerated fibers could be recognized in the thalamus, particulary in the lateral and ventral nuclei of it, but there were no degenerated fibers in the nuclei of the motor cranial nerves of the brain stem. Therefore, as stated by OGAWA[2], these numerous efferent fibers from the area 6 aβ to the lateral and ventral nuclei of the thalamus are considered to be participating in the adversive movement.

The areas 5 and 7 were named as the parietal adversive fields by FOERSTER[5]. The adversive movement from these areas is thought to be conducted by their respective corticofugal projection fibers. There are reports saying that the areas 5 and 7 are connected directly with the oculomotor nucleus, but their details are not clear. It has been clarified that the secondary degenerated fibers from the areas 5 and 7 do not directly connect with the motor nuclei of the eyeballs, but they reach the tail and the head of the caudate nucleus, as stated by OGAWA[2].

The area 19 was named as the occipital eye field by FOERSTER[5], but the adversive movement was seen by the stimulation of this area. They thought this adversive movement was conducted by the corticofugal extrapyramidal fibers from this area. As for the conduction fibers, UCHIJIMA[15] reported the fibers reaching the superior colliculus from area 19, and BARRIS[16] recognized the fibers reaching the pretectal region, superior colliculus and pupillary nuclei. In our studies the secondary degenerated fibers were revealed in the tail and the head of the caudate nucleus and homolateral superior colliculus from the area 19.

The area 22 was named as the temporal adversive field by FOERSTER[5] and as the ear field by VOGT[4]. From this area, there were observed the efferent fibers reaching the homolateral superior colliculus and oculomotor nucleus participating in the adversive movement. OGAWA[2] reported the conduction pathways of adversive movement from the area 22 connected with the caudate nucleus. By our studies, the secondary degenerated fibers from the area 22 were found in the tail and head of the caudate nucleus and the homolateral superior colliculus. The former was meager and the latter was relatively more abundant. Furthermore, after making the lesions on the areas 7, 19 and 22, degenerated granules were recognized in the homolateral superior colliculus. It is generally also considered that fibers from these areas to the superior colliculus participate in the adversive movement.

There are many reports on the movements caused by the stimulation of the diencephalon. To mention a few of these reports about the movements of eyeballs, head and neck, they are: BECHTEREW[17] recognized pupillary changes by the stimulation of the wall of the third ventricle and contraversive movement of head by the destruction of these portions. SACHS[18] found the ocular movement by stimulating the medial nucleus of the thalamus, and contraversive movement of the head by the stimulation of the lateral nucleus of the thalamus. INGRAM, RANSON and HANNETT[19] reported the contraversive movement of the head by the stimulation of the ventral nucleus of the thalamus, zona incerta, Forel's field H_1, H_2 and anterior parts of the red nucleus. HESS[20] observed the movements of the head and eyeballs by the stimulation of the surroundings of the Vicqd' Azyr's faciculus, Forel's field and the ventral and reticular nuclei of the thalamus. ISHIJIMA[21] recognized the rotation of neck by the stimulation of the ventral nucleus of the thalamus. UEMURA[22] reported the contraversive movement of head by the stimulation of the reticular, anterior, lateral and ventral nuclei of the thalamus. OGAWA[2] observed the adversive movement by the metrazol stimulation of the middle nuclear group (medial, lateral and ventral nuclei) and posterior nucleus of the thalamus, and after the removal of these nuclear groups such movements did not occur even when stimuli were given to the areas 8 and 6 $a\beta$. Therefore, he considered that there were synapses of the conduction pathways of the adversive movement from the areas 8 and 6 $a\beta$ in these nuclear groups of the thalamus, where they were joined with the second neurons from the thalamus reaching the midbrain. It has been recognized by our experiments that a large number of the corticofugal fibers from the areas 8 and 6 $a\beta$ reach the lateral and ventral nuclei of the thalamus. These facts are convenient in considering that the lateral and ventral nuclei of the thalamus participate in the adversive movement.

The efferent fibers from the thalamus to the midrain are still unknown. SACHS[18] reported the secondary degenerated fibers reaching the nuclei of the V, VI, VII, X cranial nerves through the posterior longitudinal fasciculus by making the lesions in the ventral nucleus of the thalamus. CROUCH and THOMPSON[23] reported the degenerated fibers from the ventral nucleus of the thalamus reaching the midbrain. But the portions of their termination were not clear. Therefore, we investigated the secondary degenerations by making a small lesion in the lateral and ventral nuclei of the thalamus, and demonstrated that the fibers from the lateral and ventral nuclei reached the pretectal region, superior colliculus, the upper parts of the reticular formation of the tegmentum and Cajal's interstitial nucleus. But we could not find the fibers from the thalamus reaching the nuclei of the motor cranial nerves.

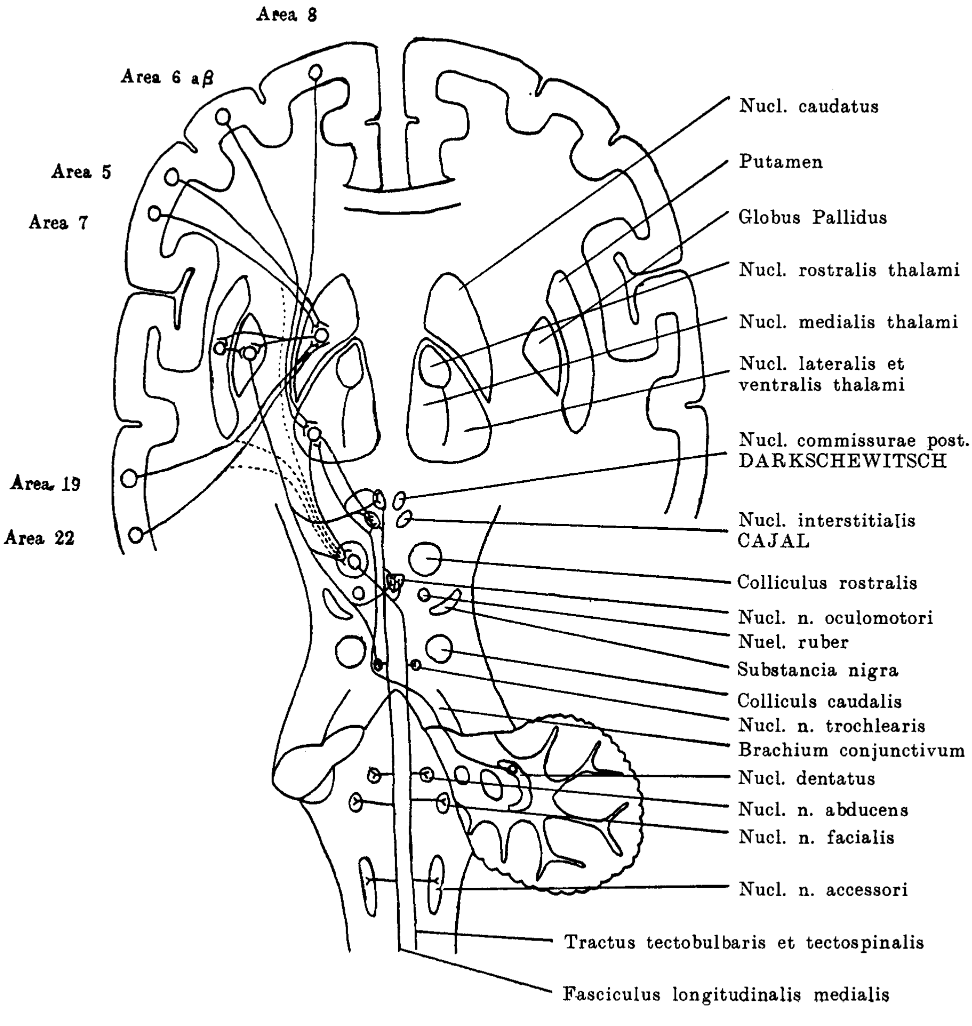
It is a common knowledge that the caudate nucleus and the lenticular nucleus are closely connected by the crossing fibers through the internal capsule and play important roles in the rigidity and co-ordinated movements of the muscles as the striopallidar system. MORGAN[24], LIDDLE and PHILLIPS[25], METTLER[26] and others reported that the movements of eyeballs, head and upper body occurred when the lenticular nucleus had been either stimulated or destroyed. OGAWA[2] also recognized the adversive movement by the stimulation of the caudate nucleus and the lenticular nucleus but he could not observe the adversive movement by the stimulation of the areas 5, 7, 19 and 22 after removing the lenticular nucleus. Therefore, he concluded that there might have been synapses of the conduction pathways of the adversive movement from the areas 5, 7, 19 and 22 in the caudate and lenticular nucleus, and then the efferent fibers from the lenticular nucleus reached the midbrain.

In our experiments, we could recognize the fibers reaching the caudate nucleus from the areas 5, 7, 19 and 22 as described previously. Furthermore, by making the lesion in the lenticular nucleus, the degenerated fibers reaching the upper parts of the reticular formation of the tegmentum, superior colliculus, Cajal's interstitial nucleus, Darkschewitsch's nucleus and oculomotor and trochlear nuclei could be recognized. These lenticofugal fibers were thought to play roles in the adversive movement.

In addition to this, by the stimulation of the superior colliculus, the adversive movement was seen clearly, and by destroying it, the degenerated fibers from the superior colliculus reached the nuclei of the oculomotor, trochlear, abducens, facial and accessory nerves. Therefore, it is considered that these fibers from the superior colliculus *i. e.* tectobulbar and tectospinal tracts are one of the conduction pathways of the adversive movement. But OGAWA[2] reported that after removing the superior colliculus the adversive movement could still occur by the stimulation of the area 5. Consequently, it is thought that these tracts partly participate in the adversive movement.

OGAWA[2] pointed out that the stimulation of the nuclei of the oculomotor, abducens, accessory nerves and so on, in the brain stem could cause the adversive mevement. But we could not clarify how they are connected and how they participate in the adversive movements. On this point, HIRASAWA[6], STRONG and ELWYN[27] stated that the medial longitudinal fasciculus is connected with the nuclei of the oculomotor, trochlear, abducens and accesory nerves and participate in the coordinated movements of the eyeballs, head and neck. The nuclei of the medial longitudinal fasciculus consist of the Darkschewitsch's nucleus, Cajal's interstitial nucleus, vestibular nucleus, motor nuclei in the brain stem, superior colliculus, corpus striatum and globus pallidus.

Fig. 24.



By our experiments it has been clarified that there are fiber connections from the thalamus and lenticular nucleus to these nuclei. Thus, these fibers are be considered to the conduction pathways of the adversive movement without passing through the superior colliculus.

OGAWA[2] reported the conduction pathways of the adversive movement from the cerebellum passed through the dentate nucleus and brachium conjunctivum, and reached the tegmentum of the midbrain and the thalamus of the contralateral side, and then joined with the conduction pathways from the adversive field of the cerebral cortex. Remarkable, degenerated fibers were found in the brachium conjunctivum after destruction of the dentate nucleus and small part of the nucleus interpositus. These degenerated fibers from there reached the red nucleus, trochlear and oculomotor nuclei, Westphal-Edinger's nucleus, Darkschewitsch's nucleus, Cajal's interstitial nucleus, Forel's field, the lateral and ventral nuclei of the thalamus and partly to the superior colliculus and the medial nucleus of the thalamus. These fibers are considered to participate in the adversive movement, because the majority of these nuclei participate in the oculogylic and cephalogylic movements as stated above.

The results as already mentioned are collected and shown in Fig. 24.

CONCLUSIONS

1. The descending fibers from the areas 8 and 6 aβ reaching the lateral and ventral nuclei of the homolateral thalamus are recognized. They are considered to be the conduction pathways of the adversive movements caused by the stimulations on the areas 8 and 6 aβ.

2. The descending fibers from the areas 5, 7, 19 and 22 reaching the head and the tail of the homolateral caudate nucleus are revealed. These fibers are considered to be the conduction pathways of the adversive movement caused by the stimulation on these areas. Moreover, the descending fibers from the areas 7, 19 and 22 reaching the homolateral superior colliculus are recognized. These fibers are also considered to participate in the adversive movement.

3. The fibers from the lateral and ventral nuclei of the thalamus reaching the homolateral superior colliculus, Cajal's interstitial nucleus and reticular formation of the mesencephalon are observed. These fibers are considered to be the conduction pathways of the adversive movement from the thalamus.

4. The caudate nucleus and the lenticular nucleus are connected closely by the numerous fiber bundles crossing the internal capsule.

5. The fibers from the lenticular nucleus which participate in the ad-

versive movements descend through the lenticular fasciculus, Forel's field, the comb-fibers in the cerebral peduncle, substantia nigra and medial lemniscus, and then reach the stratum lemnisci et profundum of the homolateral superior colliculus, Cajal's interstitial nucleus, Darkschewitsch's nucleus, Westphal-Edinger's nucleus, oculomotor nucleus and trochlear nucleus.

6. The tectobulbar tracts from the superior colliculus joined with the both oculomotors, contralateral trochlear, abducens, facial and accessory nuclei, thus they are considered to take part in the adversive movement.

7. The ascending fibers from the dentate nucleus pass through the homolateral brachium conjunctivum and reach the contralateral trochlear and oculomotor nuclei, superior colliculus and the lateral and ventral nuclei of the contralateral thalamus. These ascending fibers are considered to be the conduction pathways of the adversive movement from the cerebellum.

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