A Histological Comparison of Myelinated Nerve Fibers between the External and Extreme Capsules in Human Brain

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Abstract

Introduction: To recognize the myelinated nerve fibers of the external and extreme capsules in human brain.

Materials and Methods: 10 adult and normal brains (20 hemispheres) from both sexes were studied using 15 mm serial secions in all three cardinal planes after fixation and processing. These sections were stained by Klüver - Barrera and Heidenhin - Woelcke methods.

Results: Some fibers from different parts of the cortex through corona radiata entered the dorsal border of the external capsule, These fibers moved ventraly and ventrocaudaly toward the ventral border of the external capsule, and most of them entered the cerebral peduncles trans -, sub -, or retrolenticularly. Some fibers passed through dorsal part of putamen and connected the external capsule with posterior limb of the internal capsule. Some fibers passed between rostrum of corpus callosum and venteral part of the external capsule. Some fibers traced from the external capsule to posterior bundle of the anterior commissure; some of them entered the commissure but others terminated in nucleus basalis (Meynert) neurons. Some fibers passed through rostral part of the external and extreme capsules.

Most of the fibers of the extreme capsule interconnected the temporal and frontoparietal operculi with the insular gyri, or with each other. A group of the extreme capsule fibers connected the adjacent insular gyri with each other. Some fibers exchanged between the extreme capsule and the claustrum. There were fibers which went between the external and extreme capsules through the dorsal claustrum.

Conclusion: It is concluded that the external capsule contains all three groups of fibers, but it is mainly projectional; on the other hand, the extreme capsule is mainly associational. Thus, in our opinion, these two capsules should be classified in different groups.

Key words: External capsule, Extreme capsule, Human brain, Histological study.

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Introduction

The various parts of the white matter of the cerebral hemispheres consist of many myelinated nerve fibers which are divided into three groups: 1. association, 2. commissural, and 3. projection. Little is known concerning the relations, courses, and connections of the nerve fibers of the human cerebral white matter (1). On the other hand, more recognition of these fibers has a significant positive effect on anatomical diagnosis of neurological diseases, and probably on improvement of neurosurgical procedures. Lack of knowledge about the existence of some neural connections, or courses and relations of these connections in human cerebral white matter can be the cause of some uninterpretable observations in neural lesions.

One of the most unexplored nerve fibers of the human cerebral white matter is the nerve fibers of the external and extreme capsules. The external capsule is a part of the cerebral white matter which is limited by the claustrum lateraly and the putamen medialy. The extreme capsule is limited by the insular cortex lateraly and the claustrum medialy.

Literature in recognition of the nerve fibres which build the external capsule in the human brain is rare. Most of neuroanatomical texts represent only the topography and anatomical location of the external and extreme capsules without refering to the types of nerve fibers which build it (2-9). There are a few neuroanatomical texts which represent very brief and paradoxical descriptions about the nerve fibers of these capsules. Some of these texts classify the nerve fibers of the external capsule as the projection fibers which connect the cortical with subcortical areas (10, 11); whereas other texts lie these fibers in the association group which connect different cortical areas in the same hemisphere (12, 13). The external and extreme capsules are lain in one category (association group) by some authors (12, 13), but they are describe under different categories by others (14). Considering the controversy and lack of the exact knowledge about the nerve fibers of the external capsule in human brain, we decided to investigate more about the types of the myelinated nerve fibers of the external and extreme capsules in human brain with the aim of exact and exclusive recognition of these fibers.

Materials and Methods

Ten adult, normal human brains (20 hemispheres) without any cerebral pathology were chosen in equal ratios from both sexes. The brains were removed from the cranium no longer than 12 hours postmortem. To maintain the normal contour of the brain, the basilar artery was ligated and used to suspend the brain in the 4% formalin container.

After two weeks, the brains were relatively fixed. These brains were placed in three groups. 6 brains in coronal plane, 2 brains in parasagittal plane, and 2 other brains in horizontal plane were sectioned serially by a macrotome in 2 cm thickness.

These sections were placed in 4% formalin solution for one more week to complete the fixation. Then they were placed in 70% alcohol for one week and in 96% alcohol for another week. The samples then were dehydrated by passing through the graded alcohols. Then the stages of passing through the aceton and paraffin embedding were performed. Finally,the sections were placed within paraffin blocks. These blocks have very great size which contain both of cerebral hemispheres in coronal and horizontal sections. These paraffin blocks were serially sectioned into 15 μm sections by tetrander microtome (Jung, Heidelberg). One section from every 20 serial sections was stained (ie. sections number 1, 21, 41,...), and other sections were preserved among special papers. Principle staining used in this study was Klüver-Barrera method which makes the myelinated fibers dark blue and the cell bodies violet. The advantage of this method is showing both of the myelinated fibers and gray matter together. So the origin or ending of fibers in differnt nuclei or the cortex are obvious.

For more accuracy, one of the sections immidiately before or after that section was stained by Heidenhain - Woelcke method which makes the myelinated fibers black. In this method the cell bodies aren't stained.

Findings

In the external capsule, some fibers were seen

originated from different parts of the cortex, passed through the corona radiata and entered the dorsal border of this capsule. These fibers moved ventraly and ventrocaudaly toward the ventral border of the external capsule, and most of them entered the cerebral peduncles translenticularly, sublenticularly, or

callosum and the ventral part of the external capsule. Dorsal to these fibers, there were some fibers which connected the external capsule with the ventral part of the accumbens nucleus.

Some fibers traced from the external capsule to posterior bundle of the anterior commissure; some of

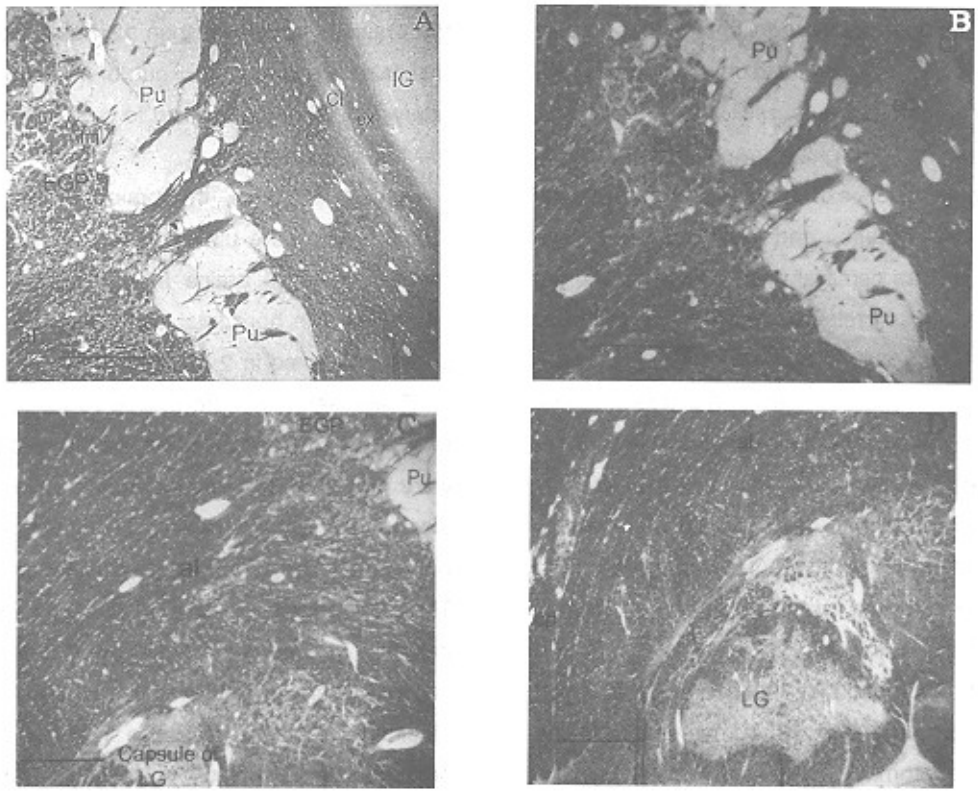

Fig. 1: A coronal section through ventral area of the posterior part ofputamen (Pu), external capsule (ec), extreme capsule (ex), claustrum (Cl), and insular gyrus (IG). Figures A to D are arranged from lateral to medial ; ie. the figures A is lateral to B, B is lateral to C, and C is lateral to D. As it is noticed the fibers from the external capsule (ec) along its course pass through the posterior part of the putamen (Pu), internal medullay lamina (Iml), external globus pallidus (EGP), and over the lateral geniculate body (LG) to enter the cerebral peduncle (Cp). The posterior part of putamen is segmented by passing of these fibers. Staining: Klüver - Barrera; Scale bar: 1mm

retrolenticularly after passing over the lateral geniculate body (Fig. 1A-D). No connection was seen between these fibers and the subthalamic nucleus or the substantia nigra. Some fibers passed through dorsal part of the putamen and connected the external capsule with the posterior limb of the internal capsule.

Some fibers exchanged between the putamen and the external capsule. Some of these fibers connected the putamen with the dorsal parts of the external capsule and the other fibers connected the putamen with the ventral parts of the external capsule (Fig. 2 and 3).

part of the external capsule, putamen, and anterior limb

them entered the commissure but others terminated in the nucleus basalis of Meynert neurons.Some fibers from frontal lobe passed through the rostral part of the external capsule , putamen , and anterior limb of the internal capsule to terminate in the medial dorsal nucleus of thalamus.The inferior longitudinal fasciculus and the uncinate fasciculus passed through the ventral part of the external and extreme capsules.

In the extreme capsule, some fibers were seen originated from frontal and parietal operculi and entered the dorsal border of this capsule. Most of these fibers which placed in lateral part of the extreme capsule terminated in the dorsal part of insular gyrus

(Fig. 4, 5). A small part of these fibers descended very near the claustrum to terminate in temporal operculum, including the auditory area, and in superior temporal gyrus.

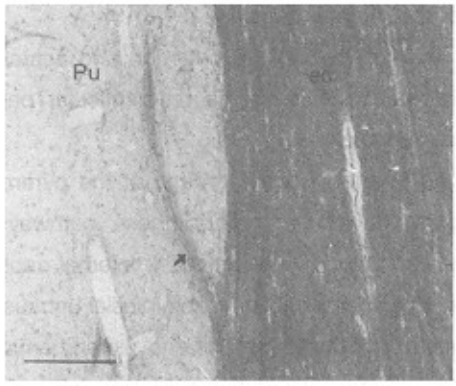

Fig. 2: A coronal section of the putamen (Pu) and external capsule (ec) at the level of the optic chiasma. As it is noticed, some of the external capsule fibers (arrow) connect the putament with the dorsal areas of the external capsule. Staining: Kluver - Barrera; Scale bar: 250 μm

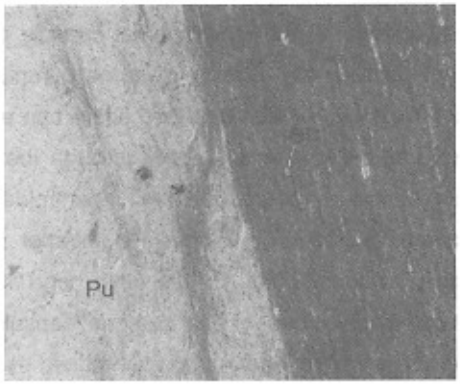

Fig. 3: This figure show the area which is situated a little below the fig. 4. Some fibers (arrow) exchange between the putamen (Pu) and the ventral part of external capsule (ec). Staining: Kluver-Barrera; Scale bar: 250 μm

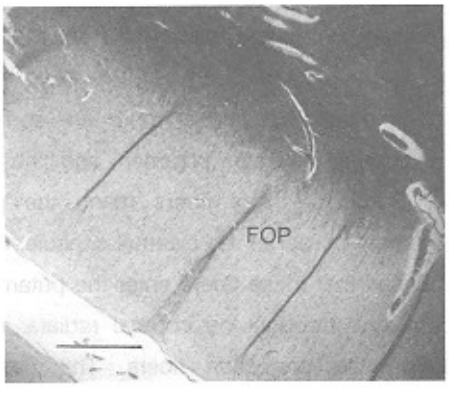

Fig. 4: A coronal section through the frontal operculum of the right hemisphere. The association fibers from frontal operculum (FOP) which arch into the dorsal border of the extreme capsule, are seen. Staining: Klüver-Barrera, Scale bar: 1 mm

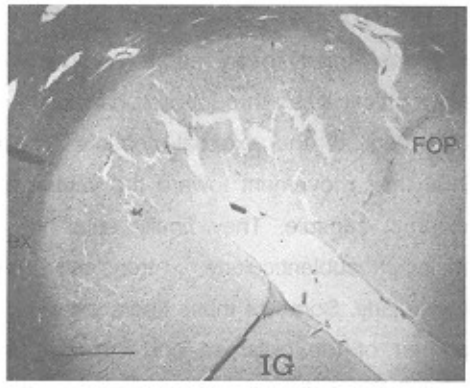

Fig. 5: The continuation of association fibers in Fig. 4 and their entering into the dorsal border of the extreme capsule is seen. The beginning of these fibers in frontal operculum (FOP) and ending of them in insular gyrus (IG) is obvious. Staining: Kluver-Barrera, Scale bar: 1mm

During this course, some fibers exchanged between the extreme capsule and the claustrum (Fig. 6). Some fibers from ventral part of the superior insular gyrus descended in the extreme capsule and terminated in two areas. Most of them which placed in lateral part of the extreme capsule terminated in dorsal part of the inferior insular gyrus; ie. they connected the adjacent insular gyri to each other. Other fibers terminated in temporal operculum and superior temporal gyrus. All of fibers from ventral part of the inferior insular gyrus, and some of fibers from claustrum terminated in temporal operculum and superior temporal gyrus.

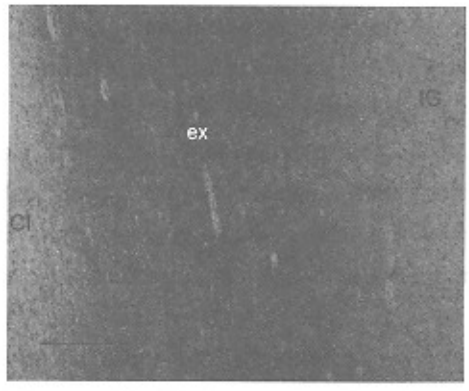

Fig. 6: A coronal section through the extreme capsule. As it is seen, some fibers exchange between the extreme capsule (ex) and the claustrum (CL) in medial part of the capsule. In lateral part of the extreme capsule, there are some fibers go between this capsule and the insular gyrus (IG). Staining: Kluver - Barrera, Scale bar: 250 mm

Some fibers exchanged between the extreme capsule and the external capsule through the dorsal claustrum.

Discussion

As it has already been reported, some fibers from different cortical areas through corona radiata enter the dorsal border of the external capsule. These fibers continue their movement toward the ventral border of the external capsule. They finally enter the cerebral peduncles sublenticularly, translenticularly, or retrolenticularly. Some of these fibers pass through the dorsal part of the putamen and so enter firstly the posterior limb of the internal capsule and then reach the cerebral peduncles together with the other fibers of the internal capsule. Since these fibers connect different areas of the cerebral cortex with the tegmentum of midbrain, they can be named as corticotegmental fibers. According to definition, these fibers are classified as the projection fibers. In monkey the Marchi method was used to follow the external capsule fibers by Berke in 1960 (15), and showed that there are corticotegmental fibers in the external capsule. The present results on human brain are consistent with previous results for monkey's brain. Since the use of exprimental methods, such as tracing and following the degenerated nerve fibers, is not ethically practicable in alive human brains, the authors could prove the existence of corticotegmental fibers in the external capsule of the human brain by a practicable method on postmortem samples. Since these fibers from different cortical areas through corona radiata and external capsule enter the posterior limb of the internal capsule or cerebral peduncles, it can be postulated that some of the pyramidal and exterapyramidal fibers which originate from different cortical areas after passing through corona radiata may enter the dorsal broder of the external capsule instead of entering the dorsal border of the internal capsule. So they separate their course from the main bundle which pass through the internal capsule. These nerve fibers intend to unify themselves with the main bundle again as soon as possible. So during their course ventraly and ventrocaudaly, they will reach finally the main bundle through one of this pathways:

1. Passing through the dorsal part of the putamen, enter the posterior limbe of the internal capsule;
2. Passing through the ventral part of the posterior end of the putamen, enter the cerebral peduncle;
3. Passing beneath the posterior end of the putamen, enter the cerebral peduncle (these fibers actually take part in the structure of the sublenticular part of the internal capsule);
4. Passing behind the putamen and actually taking part in the structure of the retrolenticular part of the internal capsule.

The passing of some groups of the pyramidal and extrapyramidal fibers through these pathways has a clinical importance. Lesions of the internal capsule lead to the spastic contralateral hemiplesia because of the involvement of the pyramidal and extrapyramidal fibers (16); but surprisingly in the spastic hemiplegia due to the lesions of the internal capsule, the paralized limb is still able to carry out some voluntary movements (16). A possible explantation can be passing of some pyramidal and extrapyramidal fibers through the external capsule. In fact, the external capsule provides an intact pathway for passing of some pyramidal and extrapyramidal fibers thereby these fibers can enter the cerebral peduncle without passing through the internal capsule. This means these pyramidal and extrapyramidal fibers by - pass the internal capsule, especially its dorsal parts. On the other hand, it can be postulated that lesions of the external capsule could lead to some limited exterapyramidal related symptoms because of the interruption of some pyramidal and extrapyramidal fibers which pass through this capsule. This postulation is supported by the report of Kleinert et al. (17) based on the appearance of the extrapyramidal symptoms follwing the external capsule necrosis.

As it is mentioned above, there are some fibers which exchange between putamen and the external capsule. Some of these fibers reach the putamen through dorsal border of the external capsule. So it can be postulated that these fibers enter the putamen from the cortex and through the coronal radiata; therefore they belong to projection fibers. The passing of corticostriate fibers which connect the different areas of the cortex with the putamen, through the external capsule is proved in monkey's brain (10,15); but according to williams et al. (10) These findings can not

be extrapolated to human brain without adequate evidence in human beings because of many different findings which are found among various mammals. The findings of this study provide evidences which help us to extrapolate the existence of corticostriate fibers in the external capsule to human brain. Although this method is not able to determine that these connections are afferent or efferent, but according to the classic information the connection between the cortex and the corpus striatum must be afferent type (10).

Some of the fibers which connect the putamen with the external capsule enter from the ventral border of this capsule. It seems these fibers reach the putamen through long association bundles which lie in ventral part of the external capsule (such as the uncinate fasciculus) from frontal, temporal, and occipital cortices. The current results report such a connection for the first time. These fibers also belong to the projection fibers.

In this study, no connection is found between the external capsule fibers which enter the cerebral peduncle and subthalamic nucleus or substantica nigra. Williams et al. (10) presented the connection between the subthalamic nucleus and these fibers in monkey's brain, Kaelber and Afifi (18) also reported the connection between these fibers and lateral part of substantia nigra in cat's brain. There are two factors which can explain the difference between our findings and the findings of williams et al. or Kaelber & Afifi:

1. The first factor is the difference between the materials of the studies; for instance, Williams et al's findings are obtained from monkey's brain and Kaelber and Afifi's findings are based on cat's brain, whereas our findings are based on human brain; 2. The second factor is the difference between the methods of the studies; for example, in spite of their accuracy, due to some ethical reasons the authors were not allowed to use experimental methods on human brain. Furthermore, the current study was limited to the myelinated nerve fibers, so there could be some unmyelinated nerve fibers which connect the external capsule with the subthalamic nucleus or the substantia nigra and therefor, were neglected by the present mehtod. On the other hand, Williams et al. (2) Overlooked the importance of these conections in their book.

The existence of connection between nucleus basalis of Meynert and the external capsule correlate with findings of Cholinergic Pathways Investigations in the brain (19, 20, 21, 22, 23). Today it is believed that some of cholinergic fibers which originate from nucleus basalis of Meynert and terminate in neocortical parts of the brain pass through the external capsule (23).

In this study, the connection between the external capsule and the ventral part of the accumbens nucleus is proved in human brain. This finding is in line with Groenewegen's opinion (24) which states the cortical afferent fibers in cat's brain reach the ventral part of the accumbens nucleus through the external capsule.

The connection found, in the present study, between corpus callosum and the external capsule is being reported by the authors for the first time. These fibers as well as the fibers which enter the external capsule from anterior commissure belong to the group of commissural fibers.

As it has already been menioned, the inferior longitudinal fasciculus and the uncinate fasciculus which belong to the long and well - known association fibers pass through the ventral part of the external and extreme capsules. So the third group of fibers, the association fibers, also exists in the external capsule.

So it is concluded that the external capsule contains all three groups of fibers (projection, association, and commissural), but the main components of its fibers are projectional, particularly in dorsal parts.

The results of present study revealed that there are three categories of the associational fibers in the extreme capsule: 1. The fibers that belong to the long association bundles, such as the uncinate and occipitofrontal fasciculi; 2. The short association fibers that connect the adjacent gyri of the insula to each other; 3. The associational fibers that interconnect the temporal operculum and the superior temporal gyrus with the frontal and parietal operculi directly via the medial part of the extreme capsule. These latter fibers cannot be classified as the short association fibers,

because they don't connect the adjacent gyri to each other. So, these fibers should be classified either as the long association fibers which have yet no definitive name of, in our opinion, as a new and independent group of association fibers named" the intermediate association fibers".

Although our findings in the extreme capsule of the human brain have more similarities to those in the monkey's brain (15) than to those in the dog's brain (25), there are some differences between the findings in the human brain and the mankey's brain.

There are some fibers in monkey's brain which interconnect the middle and the inferior temporal gyri with the frontoparietal operculum, while in our study such connections were not seen.

The fibers connect the temporal operculum, including the auditory crtex, with frontoparietal operculum, icluding the motor speech area of Broca, may play a very important role in speech process. It is postulated if these association fibers are destroyed in a extreme capsular lesion, the patient may suffer from a special kind of aphasia named conduction aphasia since this lesion destroys the connection between the auditory and the motor speech areas of cerebral cortex. This postulation is supported by many clinical reports, including the recent report of Kreisler et al. (26).

As mentioned above, some fibers exchange between the claustrum and the extreme capsule. These fibers are belong to projectional fibers, according to definition.

So it is concluded the extreme capsule contains both of the association and projection fibers, but it is mainly associational.

Our study revealed the external and extreme capsules in spite of very close relation topogyraphically are different in the type of their fibers. The externalcapsule is mainly projectional and the extreme capsule is mainly associational. So, in our opinion, these two capsules should be classified in different groups based on the type of their fibers.

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