ÖZGÜN ARAŞTIRMA ORIGINAL RESEARCH

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MICROSURGICAL ANATOMY OF THE CONNECTIONS OF CAUDATE NUCLEUS AND PSYCHOSURGICAL CONSIDERATIONS : A UNIQUE CADAVER STUDY

KAUDAT NUKLEUS BAĞLANTI YOLLARI MİKROCERRAHİ ANATOMİSİ'NİN PSİKOŞİRÜRJİKAL ÖNEMİ: ÖZGÜN KADAVRA ARAŞTIRMA ÇALIŞMASI

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Öz

Amaç
Nükleus kaudatus bazı nörolojik ve psikiyatrik hastalıkların tedavisinde bir hedef olabilir mi diye tartışılmaktadır. Mikrocerrahi girişimler ve stereotaksik yaklaşımlar için kaudat nükleus bağlantılarının daha açık bir şekilde tanımlanması gerekmektedir. Bu çalışmamızda nükleus kaudatus mikrocerrahi anatomisini ve bağlantı yollarını fiber diseksiyon tekniği kullanarak ortaya koymayı ve bunun psikoşirürjikal önemini orrtaya koymayı amaçladık.

Gereç ve Yöntem
Dört adet formalinle fikse edilmiş insan beyni (8 hemisfer) detaylı şekilde incelendi. Tüm örnekler Klingler' in tekniğine göre -16 °C'de en az 15 gün donduruldu ve birkaç saat boyunca su altında çözülmeleri sağlandı. X6 ila x40 mikroskopik büyütme altında ak madde lif diseksiyonu gerçekleştirildi. Tüm beyin hemisferleri, lateralden mediale doğru kaudat nükleusun başı ve gövdesi ortaya çıkana kadar olarak disseke edildi. Ayrıca, adım adım iki ve üç boyutlu fotoğraflar çekildi.

Bulgular
Nükleus kaudatus etrafındaki tüm yapılar kademeli olarak diseke edildi. Bu yapı ile iletişim halinde olan ve fiziksel olarak temas eden tüm kortikal alanlar gözden geçirildi. Frontokaudat ve frontotemporal bağlantıların mikrocerrahi anatomisi ayrıntılı ortaya konuldu.

Sonuç
Psikoşirürji, medikal tedavilerin henüz gelişmediği dönemlerde, depresyon tedavisinde öncelikli olarak kullanılmıştır. Kaudat nükleusa yönelik yapılan derin beyin stimülasyonu klinik pratikte standart bir tedavi yöntemi değildir ama Parkinson hastalığı, obsesif kompülsif hastalık ve majör depresyonda alternatif tedavi olabilir.

Anahtar Kelimeler: Nükleus kaudatus, psikoşirurji, ak madde, anatomi, bağlantı

Abstract

Objective
Caudate nucleus has been discussed as a target for new treatments of neurologic and psychiatric diseases but the connectivity remains unclear for both microsurgical procedures and stereotactic interventions despite the basic neuroanatomical knowledge. We aim to reveal the anatomic features of the caudate nucleus in psychiatric diseases using fiber dissection technique.

Material and Methods
Four brain specimens (8 Hemispheres) were frozen

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for 15 days at -16 °C according to Klingler's Technique. The freezing process facilitates the dissection of the fiber tracts. After completion of the freezing process, all of the hemispheres were dissected and the dissections were stepwise performed from lateral to medial, under x6 to x40 magnification using a surgical microscope, two and three-dimensional anatomic pictures were obtained.

Results
Stepwise microsurgical fiber dissection of the caudate nucleus and adjacent areas were dissected. The cortical areas communicating with and overlying the caudate nucleus are reviewed. Frontocaudate connection fibers and temporocaudate fibers were intense and the microsurgical anatomy of the area were revealed. Two and three dimetional pictures were taken step by step.

Conclusion
Psychosurgery has been used primarily in treatment of depression when medical treatments were not adequate. Deep brain stimulation of caudate nucleus is not a standard method in clinical practice. Deep brain stimulation of caudate nucleus is not a standard method in clinical practice but it could be an alternate treatment for Parkinson's disease, obsessive compulsive disorder and major depression.

Keywords: Caudate nucleus, psychosurgery, white matter, anatomy, connection

Introduction

The basal ganglia are the main structures of the brain related to sensorimotor coordination, including initiation and selection of response (1). Caudate nucleus (CN) is one of the basic structure of the basal ganglia (1, 2). There are two CN of the brain within the right and left hemispheres. The head of CN is the widest C-shape component at the front, and the other parts are called as a "body" (corpus) and a "tail" (cauda). The head and body of CN form part of the floor of the anterior horn of the lateral ventricle. The roof of the inferior horn of the lateral ventricle is formed by the tail of CN after traveling the body around the back of head (3-5). CN is a critical structure in regulating mood, some aspects of cognition, motor function and motivation. Also, psychomotor speed and treatment resistance are associated with that region abnormalities (6-8). Better pathophysiologic and neuroanatomical knowledge play a critical role to more effective approaches to prevention and treatment of the related disseases. Excellent correlation of the fiber tract dissections of white matter with new neuroimaging techniques have led in growing interest in investigating abnormalities in the brain structure (9-12). CN and thalamus extend medially of the internal capsule. They are located medially of the central core. Although the anterior portion of the central core is associated with the head of the CN, the posterior portion is associated with the thalamus (13, 14). CN plays an important role in voluntary movement, learning, memory, sleep and social behavior. Also, it can contribute to behavior through selection of appropriate sub-targets, based on the stimulation of correct action schemes and evaluation of action outcomes. Both results can be accepted as the main processes for successful targeted action (3, 15). The modular understanding of the striatum is consistent with planned, (sensorimotor coordination; putamen) effective and hierarchical models of corticostriatal function in which adaptive behavior towards key goals (motivation; ventral striatum) can be defined (16-19). CN has been discussed as a target for new treatments of neurologic and psychiatric diseases but the connectivity remains unclear for both microsurgical procedures and stereotactic interventions despite the basic neuroanatomical knowledge (20-24). We aim to reveal the anatomic relationship of the CN and the role in psychiatric diseases using fiber dissection technique.

Material and Methods

Four formalin-fixed human brains (8 hemispheres) were examined. All specimens were frozen at -16 C at least 15 days and were allowed to thaw under water for several hours (25). After completion of the freezing process, the specimens were thawed, and the fiber tracts were dissected using micro dissectors under x6 to x40 magnifications provided by a Zeiss Surgical Microscope (Carl Zeiss AG, Germany). The dissections were performed in a stepwise manner, from lateral to medial and medial to lateral using the fiber dissection technique and the microscope , until the head and body of the CN were revealed. Two- and 3-dimensional digital photographs in all stages were taken using a Canon T5 Rebel digital camera (Canon, Tokyo, Japan) to demonstrate the structures at each step of the dissection. The microsurgical anatomy of CN and its connections and relationship were studied.

Results

The dissection was performed from lateral to medial. After removing the cortical grey matter, the dissection was extended from the superior temporal gyrus to the other superficial areas. After removing the cortical grey matter, the dissection was extended from the superior temporal gyrus to the other superficial areas. Then, we continued to the operculum with preserving the insula and the U fibers were posed. At the level of medial frontal gyrus, the superior longitudinal fascicle was revealed. The white matter of the operculum preserved because the fascicle fibers can be damaged easily. Wite matter of the opercular area were removed with sharp dissection to expose the insula. Stepwise dissection reveals the superior longitudinal fascicle more clearly. The ventral external capsule can be exposed by removing the extreme capsule. Especially, claustrum is seen evidently at the level of insular apex, and occipitofrontal and unsinate fascicle were observed at the level of limen insula. CN has very intense connections which associated with frontal and temporal lobe. Frontocaudate connections are gathered at the anterior part of the lateral ventricle and slightly superior to head of the CN. The medial surface of left cerebral hemisphere was dissected meticulously and the epandyma of the left CN and the lateral ventricle was extracted. CN was been exposed with its adjacent fiber systems (Figure 1). Temporocaudate connections have shorter paths according to frontoparietal fibers but have a tendancy to merge with amygdala-hippocampal complex fibers. The progressive resection of the uncinate and occipito-frontal fascicle reveals the amygdala that forms the anterior and upper part of the temporal horn. The CN has 3 components and surrounds the thalamus. The head of the CN is oval and located in the anterior portion of the thalamus and represents the mid-anterior portion of the central core. Foramen monro is an anatomic landmark for the transition between the head and body of the CN. If the internal capsule is carefully dissected and the head and body of CN and thalamus is visible. The body of CN surrounds the thalamus, and it continues as the tail and it leaves the thalamus in mid-posterior direction and takes a more lateral position. Stepwise decortication was firstly performed to reveal out the deep fibers around the CN. Central core has been dissected to expose putamen, CN, claustrum, globus pallidus interna and externa. Underneath lies the limen insula inferior frontooccipital fasciculus and uncinate fasciculus. The epandyma of the lateral ventricle has been shown after the CN has been partially dissected (Figure 2). The tail of the CN gradually shrinks and continues along the roof of the temporal horn towards the amygdala. Ansa peduncularis, which connects the amygdaloid nucleus to the hypothalamus, thalamus and septal region, also becomes visible. Frontal lobe, parietal lobe and occipital lobe has been totally extracted during dissection of some hemispheres to show the connections of CN. The innsula is preserved and lateral temporal lobe has been cutted preserving amygdala and hippocampus. CN has intense connections with putamen through Internal capsule. Frontocaudate and temporocaudate connections are condensed and merged with surrounding fiber systems (Figure 3).

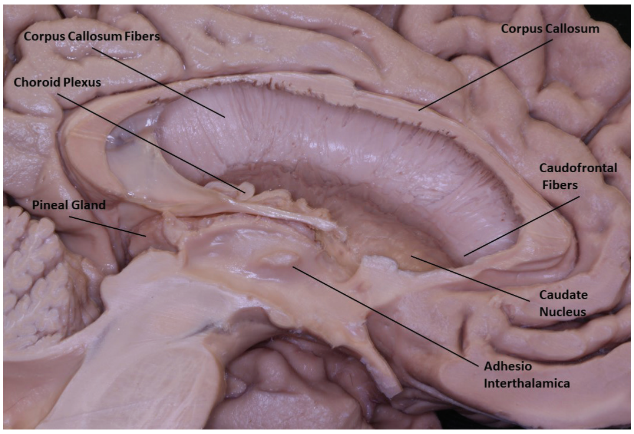

Figure 1: Medial surface of left cerebral hemisphere. The epandyma of the left caudate nucleus and Lateral ventricle has been extracted. Caudate nucleus has been exposed with its adjacent fiber systems. Especially caudofrontal fibers can be seen which are considered to have deep impact on cognitive and behavioral functions.

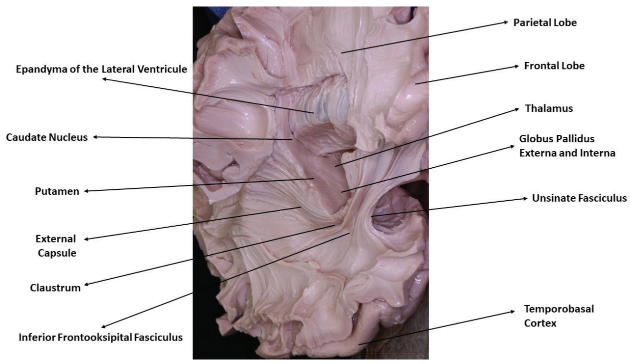

Figure 2: Right cerebral hemisphere can be seen from anterior view. Decortication previously performed in order to reveal out the deep fiber systems around the Caudate nucleus. Central core has been cutted to expose putamen, caudate nucleus claustrum ,globus pallidus interna and externa. Underneath the limen insula inferior frontooccipital fasciculus and uncinate fasciculus lies. The epandyma of the lateral ventricle can be seen from lateral view after the caudate nucleus has been partially dissected.

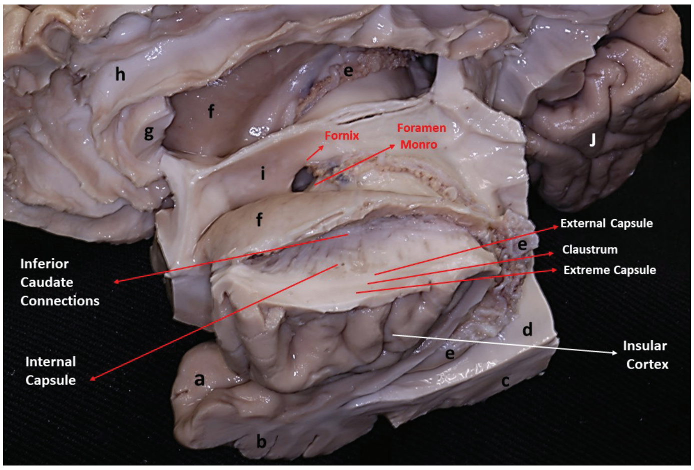

Figure 3: Lateral oblique view of left cerebral hemisphere. Frontal lobe, parietal lobe and occipital lobe has been totally extracted to show the connections of caudate nucleus. Insula is preserved and lateral temporal lobe has been cutted preserving amygdala and hippocampus. Caudate nucleus has intense connections with putamen through internal capsule. Frontocaudate and temporocaudate connections are condensed and merged with surraounding fiber systems.
a. temporal pole, **b.** temoporobasal cortex , **c.** entorhinal cortex , **d.** ventricle epandyma, **e.** choroid plexus covering hippocampus, **f.** caudate nucleus, **g.** corpus callosum , **h.** decorticated cingulate gyrus **i.** septum pellicidum, **j.** occipital lobe

Discussion

The central core stands as a block on the brainstem, at the morphological center of the supratentorial compartment (26, 27). It has a responsibility to regulate the voluntary movement. and is associated with the putamen and globus pallidus, as well in conjunction with the thalamus and the substantia nigra and subthalamic nucleus (26-28). In literature, many researchers reported that this region also plays important role in various motor and cognitive functions and has been implicated with voluntary movement, learning, memory, sleep, and social behavior (27, 28). Tasks featuring spatial and motoric memory demands effects the CN activity more than those involved in non-spatial ones (30). Also, spatial working memory activity has been observed, using functional magnetic resonance imaging studies of delayed recognition, to be greater in the CN when the activity immediately preceded a motor response. Even these results, may be preoccupied that the CN could be involved in coding a motor response (30, 31). The CN can control the body and limbs posture, the speed and accuracy of directed movements. CN has a “motor release mechanism” and that it may be indicated the procedure indicates that the CN inhibits the tendency for an animal to move forward without resistance. It supports the idea that the CN has an inhibitory function in directed movements mechanism (32). The cognitive functions of the CN are target directed actions, learning and memorial activities, sleep, emotion, language and threshold control. Executive functioning is under control of CN and it assists some of our decision-making processes (33-35). CN may play a critical role in deficits involving working memory from before illness onset as well. Because, many researchers indicated that its volume has been analyzed to be inversely associated with on spatial working memory tasks (35-37). The tail and body of the CN may be responsible to regulate the activity associated with successful classification learning. The other portions, its head has a duty that to control the activity associated with feedback processing was concentrated to the head of the CN (37-41). Many studies claimed that the CN is associated with responses to visual beauty, and has been suggested as one of the "neural correlates of romantic love". Reports of human patients with selective damage to the CN have been verified the findings about these functions (42, 43). Some studies performed on people who can speak more than one language found that the CN as a center for language control to activate exactly the same brain regions regardless of the language (41, 44). Also, CN has a regulatory role by measuring the general activity of cerebral cortex and controlling the threshold potential (40). Association between CN volume and the short allele of the 5HTT serotonin transporter gene has been emphasized in some studies (9, 45). In addition, atrophic CN correlates with visual cognitive and cognitive propositions resulting from genetic polymorphism. The area which has the highest concentration of D2 dopamine receptor (DRD2) of the brain is CN and it was assumed that genetic variations could modulate neuropsychology in this polymorphism (16, 46, 47). Under pathologic conditions of CN patients can develop various behavioral and personality changes, speech disorders and memory loss without any focal neurological signs (48, 49). Behavioral abnormalities are mostly caused by medial, lateral and ventral caudate subnucleus damage and lesions accompanied by the forearm of the internal capsule (48-52). Our dissection revealed that frontocaudate connections pass through a very small area and spreaded to frontal lobe. The destructions of these connections could have a resposibility in mental and cognitive changes during head of CN hemorrhages. Our dissections revealed no left or right difference between two hemisphere frontocaudate connections even if isolated left CN infarcts may be associated with cognitive dysfunction and mild motor speech impairment. If the lesion commonly affects putamen, confusion and motor abnormalities may occur. Extensive CN involvement can cause motor and various neuropsychological abnormalities. Large deep CN infarction with non-fluent aphasia can be reason of recurrent amomaly, transcortical motor aphasia, and global aphasia. Verbal and visual amnesia, anomy and ideomotor and buccolingual apraxia are other characteristics of left CN infarctions (48-50, 53). Parkinson's disease is closely associated with CN functions probably, loss of dopaminergic stimulation in CN is the cause of cognitive symptoms such as impaired performance of targeted actions (54, 55). Alzheimer's disease has also been associated with CN. There are some studies suggesting that the volume of CN is significantly decreased in individuals with Alzheimer's disease compared to healthy adults (56, 57). One of the diseases thought to be associated with CN is obsessive compulsive disorder. In patients receiving paroxetine, the highest increase in glucose metabolism has been shown to occur in the right CN. Morphometric studies showed that volume of CN was higher than healthy people. As a result our research has shown intense connections between thalamus and frontal lobe which merges with frontocaudate fibers, it has been suggested that there is function loss of functions of CN and that the information transmitted to the orbitofrontal cortex via thalamus related to worrying events and ideas is impaired by the nucleus (58-60). CN may also be associated with autism. It has been reported that there is a significant increase in CN volume in children with autism compared to healthy children and that there is a positive relationship between core volume and repetitive behaviors (61). Studies show that absolute and relative white matter levels in patients with schizophrenia were significantly lower than healthy people (20, 62). In 20th century, neuromodulation techniques have been preferred more than the traditional lobectomy methods. In 1986, psychosurgical techniques and nerve stimulation techniques have been mentioned by some researchers (63, 64). Stimulation techniques (deep brain stimulation, DBS) were successful in patient with dystonia and tremor. DBS was first performed in treating a patient with obsessive-compulsive disorder (65, 66). Open surgical CN implantation is based on the first experimental studies targeting dopamine-producing tissues from the adrenal medulla of Parkinson's patients in motor dysfunction (67-70). Some patients had moderate improvement and some had significant improvement. This approach was abandoned because of the short duration of this effect and significant complications such as prolonged coma. Although complications were reduced by direct injection of adrenal medulla tissues into the head of the CN with stereotactic surgery, this approach was not widely used due to the fact that the positive effect was transient and caused a trauma including excision of the adrenal medulla. It has been reported that depression and anxiety symptoms decreased significantly in a patient with obsessive-compulsive disorder and depression after the application of DBS-CN to the ventral section (23, 71). Our dissections revealed that the highest concentration of frontocaudate connections are located not directly anterior to the head of CN but rather superoanterior to the connection point of lateral ventricle and CN. DBS for CN can also be used in epilepsy. Bilateral CN stimulation was applied after each correct response in these cases based on the principle of viewing associated images and associative learning test. It has been suggested that correct response stimulation significantly increases associative learning in cases and that CN stimulation may be a potential target for modulation of memory disorders in humans (72, 73). There is no consensus about the surgical treatment of the neuropsychiatric diseases. Most of cases with severe psychiatric disease are treated with modern approaches such as pharmacological and electroconvulsive methods. Cases with severe and resistant psychiatric disease can not respond to all treatments and continue to live with their disabilities. Better understanding the surgery and its advantages in these patients and the effect of psychosurgery on this field must be considered (68, 73). DBS is most commonly preferred for Parkinson's disease. However, its efficacy in movement disorders and treatment-resistant depression should also be investigated (70, 74, 75). CN tail section damage is presented with deterioration of visual discrimination tests , However, damaging of the other CN components did not cause any deterioration. On the other hand, the damage to the head of CN caused a serious defect in the alternation tests based on the detection. Our dissections confirmed a complex anatomy of CN with adjacent connection systems and a three dimentional understanding of microsurgical neuroanatomy.

Conclusion

CN and its surrounding connection fibers have a complex three dimentional anatomy. Undrestanding the microsurgical intense struction relationships of deep brain structures, cortex and fiber systems with CN can help in developing new surgical targets for both microsurgery and neuromodulaton in the name of psychosurgery.

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