Ann Med Res 2020;27(10):2683-7

Annals of Medical Research
DOI: 10.5455/annalsmedres.2020.05.426

Original Article

Microsurgical anatomy of middle longitudinal fasciculus

Seckin Aydin[1], Aysegul Esen Aydin[2]

[1]Department of Neurosurgery, Okmeydani Training and Research Hospital, Istanbul, Turkey
[2]Department of Neurosurgery, Istanbul Bakirkoy Prof. Dr. Mazhar Osman Mental Health and Neurological Diseases Training and Research Hospital, Istanbul, Turkey

Abstract

Aim: Middle longitudinal fasciculus (MdLF) is a cortico-cortical association pathway, and originates from the temporal pole, then extends across the superior temporal gyrus and reaches the inferior parietal lobe. The aim of this anatomical study is to delineate the microsurgical anatomy of MdLF using fiber dissection technique.

Material and Methods: Four formalin-fixed cadaveric human brains were dissected by Klingler method. A step-by-step dissection was utilized to expose white matter pathways, including MdLF.

Results: MdLF consists of three parts: anterior, middle and posterior. The anterior part of MdLF fibers originates from the temporal pole and extends to posterior along the superior temporal gyrus. The middle part of MdLF is extended from the posterior of the Heschl gyrus to the medial of the arcuate fasciculus. The posterior part of MdLF joined the sagittal stratum together with the posterior limb of the internal capsule and inferior frontooccipital fasciculus.

Conclusion: MdLF is still being studied in terms of its anatomy and functions. Considering the connections between the cortical areas with well-known functions such as superior temporal gyrus, angular gyrus and superior parietal lobule, it can be asserted that MdLF is associated with language, auditory, visual and cognitive functions.

Keywords: Dissection; middle longitudinal fasciculus; neuroanatomy; white matter

INTRODUCTION

White matter pathways of the brain are examined in 5 parts in terms of location and function. These are brainstem fibers, limbic system fibers, projection fibers extending from the brainstem to the cortex, commissural fibers that connect the two hemispheres, and finally association fibers that connect different cortical structures in the same hemisphere (1,2). Middle longitudinal fasciculus (MdLF) is one of these association fibers, and originates from the temporal pole, then extends across the superior temporal gyrus (STG) and reaches the inferior parietal lobe (IPL) (3). In recent years, some authors have been suggested that this fiber bundle is related to language, auditory, visual and cognitive functions (4-7). In this study, we aimed to delineate the microsurgical anatomy of MdLF, including the adjacent structures by white matter dissection method.

MATERIAL and METHODS

Four adult human cadaveric brains were fixed in 10% formalin solution for at least 2 months according to Klingler's technique. After removing the arachnoid matter, pia matter and vascular structures, specimens were frozen at -16 C for at least 2 weeks. Before white matter dissection, cadaveric brains were prepared by dissolving under tap water. In the inter-dissection period, the brain hemispheres were kept in room temperature in 70% alcohol solution. Dissections were performed under a surgical microscope at X6 and X40 magnification using microsurgical instruments. Stepwise dissection of the neural structures was performed from lateral to medial direction. The relationship between the exposing fibers and anatomical structures was shown at each stage. All stages of the dissection were recorded with a professional digital camera and macro 100 mm lenses. This study was approved by the institutional ethics committee.

RESULTS

Initially, the gray matter of the lateral surfaces of the brain hemispheres was removed. Then, U fibers, short association fibers that connect adjacent cortical areas, were encountered. After removing the U fibers, superior longitudinal fasciculus 2 (SLF 2) and SLF 3 were exposed. SLF 2 originates from the angular gyrus (AG) and extends towards to the middle portion of the middle frontal gyrus. SLF 3 originates from the supramarginal gyrus and extends to the pars triangularis and pars opercularis of

Received: 03.05.2020 **Accepted:** 28.09.2020 **Available online:** 21.10.2020
Corresponding Author: Seckin Aydin, Department of Neurosurgery, Okmeydani Training and Research Hospital, Istanbul, Turkey
E-mail: seckin047@hotmail.com

the inferior frontal gyrus. The ventral component of the arcuate fasciculus (AF) is located in the inferolateral of SLF 2 and inferomedial of SLF 3. As the dissection is carried forward, SLF 2, SLF 3 fibers, and the posterior parts of the superior and middle temporal gyri were removed to expose the dorsal component of AF and the anterior part of MdLF. The dorsal component of AF originates from the posterior 1 \ 3 of the middle and inferior temporal gyrus, extends inferiorly along the SLF 2, and terminates in the posterior and middle portions of the middle frontal gyrus. The anterior part of MdLF originates from the temporal pole and extends to posterior along the STG (Figure 1).

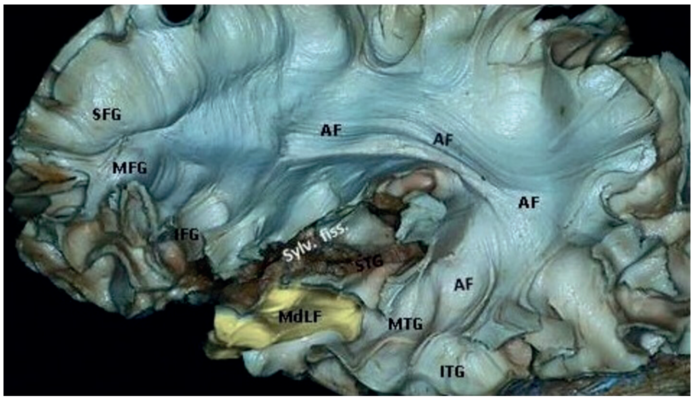

Figure 1. Dissections are made from lateral to medial direction in the left hemisphere. Arcuate fasciculus with frontal and temporal extension is exposed with the removal of superior longitudinal fasciculus 2 and 3 fibers. The anterior part of middle longitudinal fasciculus originating from temporal pole is shown with the dissection of superior temporal gyrus. The anterior part of middle longitudinal fasciculus is shown in yellow colour. AF: Arcuate fasciculus. IFG: Inferior frontal gyrus, ITG: Inferior temporal gyrus, MdLF: Middle longitudinal fasciculus, MFG: Middle frontal gyrus, MTG: Middle temporal gyrus, Sylv fiss: Sylvian fissure, SFG: Superior frontal gyrus, STG: Superior temporal gyrus.

After removing the frontal, parietal and temporal operculums, insula was exposed in the aperture of the Sylvian fissure. The anterior and middle portions of the STG were removed and the rest of the anterior part of MdLF was visualized (Figure 2). Heschl gyrus was dissected and shortened. Thus, the middle part of MdLF, which extended from the posterior of the Heschl gyrus to the medial of the AF, was observed (Figure 3).

The gray matter of the insula and the extreme capsule was removed. Dorsal external capsule consisting of dorsal claustrum and claustrocortical fibers was exposed. It was observed that the middle part of MdLF was located in the posterolateral of the dorsal component and superolateral of the ventral component of the external capsule, and medial of the AF (Figure 4). Uncinate fasciculus, inferior frontooccipital fasciculus (IFOF), putamen and internal capsule are exposed by removing the claustrum and external capsule. Uncinate fasciculus connects frontoorbital and frontobasal areas to temporal pole and amygdala. IFOF contains fibers from Broca, orbitofrontal and prefrontal areas. IFOF, which is an association pathway, passes through the external capsule and course in the middle and inferior temporal gyrus and terminates in the occipital areas.

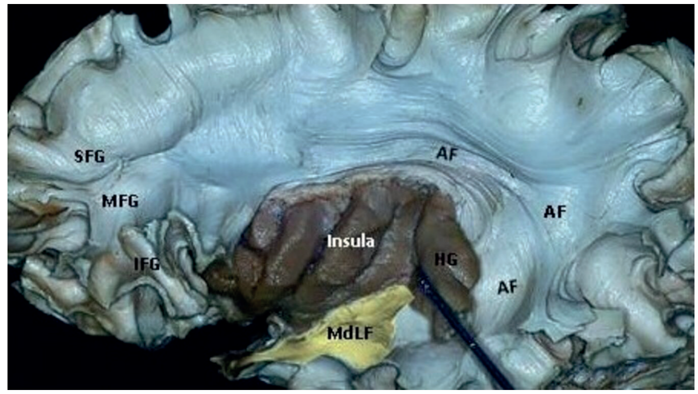

Figure 2. After removing the frontal and temporal opercula around the Sylvian fissure, the insula is exposed. Superior temporal gyrus is removed by preserving the Heschl gyrus, and middle longitudinal fasciculus extending from the temporal pole to the Heschl gyrus are shown. The anterior part of middle longitudinal fasciculus is shown in yellow colour with the rest part. AF: Arcuate fasciculus. HG: Heschl gyrus, IFG: Inferior frontal gyrus, ITG: Inferior temporal gyrus, MdLF: Middle longitudinal fasciculus, MFG: Middle frontal gyrus, MTG: Middle temporal gyrus, SFG: Superior frontal gyrus

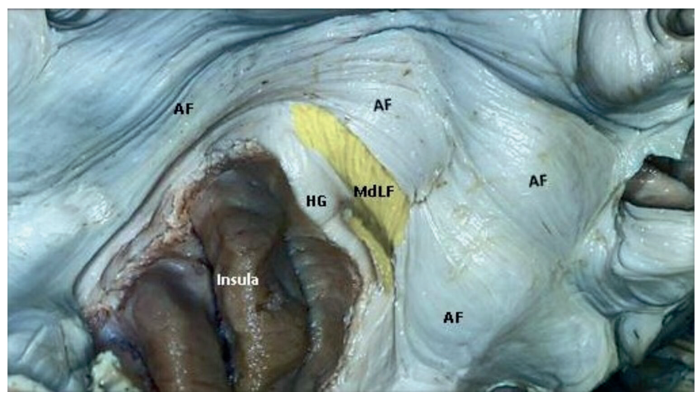

Figure 3. A close view focusing on the posterior insular region. Heschl gyrus is decorticated. The middle part of middle longitudinal fasciculus located at the posterior of Heschl gyrus is shown in yellow colour. AF: Arcuate fasciculus, HG: Heschl gyrus, MdLF: Middle longitudinal fasciculus

Putamen, the most lateral part of lentiform nucleus (LN), is located medially in the claustrum and external capsule. It was observed that MdLF fibers in the lateral and posterior of the putamen traced in the superolateral of the IFOF and medial of the AF (Figure 5). Globus pallidus is another component of LN. This rigid, dark and rounded shape structure is localized medial of the putamen. Globus pallidus is also located lateral to the genu of the internal capsule. Globus pallidus and internal capsule were exposed with the removal of the putamen. The internal capsule is divided into five sections: anterior limb, genu, posterior limb, retrolenticular and sublenticular portions.

Anterior limb is located medially between the caudate nucleus head and the lateral LN and contains frontopontin

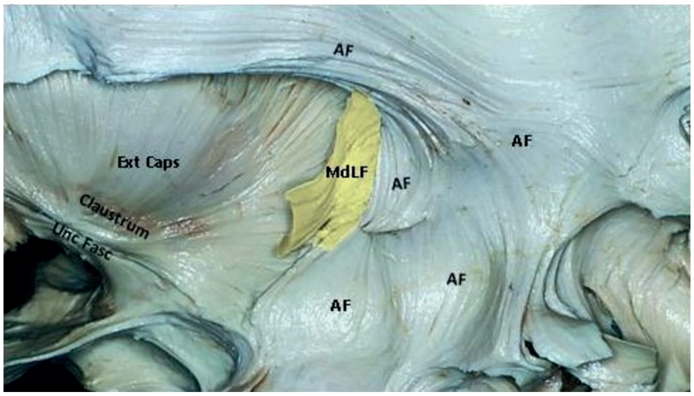

Figure 4. The gray matter of the insula, heschl gyrus, and extreme capsule are removed. External capsule, claustrum and uncinate fasciculus are exposed. The middle part of middle longitudinal fasciculus which located at the medial of arcuat fasciculus is shown in yellow colour. AF: Arcuate fasciculus. Ext Caps: External capsule, MdLF: Middle longitudinal fasciculus, Unc Fasc: Uncinate fasciculus

Posterior limb is located medially between the thalamus and the lateral LN and contains fibers extending from the precentral and postcentral gyri to the bulbus. Anterior and posterior limbs merge at the most medial part of the internal capsule (genu). Retrolenticular and sublenticular portions are located in the posteroinferior of the LN respectively and join the sagittal stratum. As the dissection was carried forward, it was seen that the retrolenticular portion remained in the inferomedial of MdLF. At the inferior of the globus pallidus, the fibers of the optic radiatio (Meyer loop) and the retrolenticular portion of the internal capsule intermingled with the anterior commissure fibers which extending towards to posterior. Thereafter, these fibers join the sagittal stratum. Also, it was observed that the posterior part of MdLF joined the sagittal stratum together with the posterior limb of the internal capsule (Figure 6).

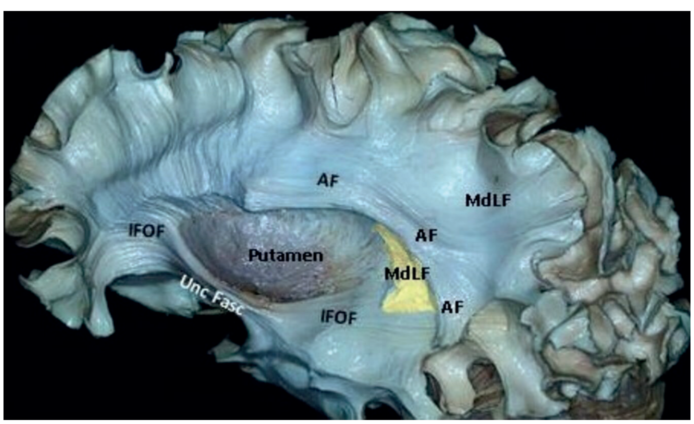

Figure 5: Inferior frontooccipital fasciculus and putamen are exposed by dissection of the external capsule and claustrum. Middle longitudinal fasciculus is shown in yellow colour while passing through the sagittal stratum level. AF: Arcuate fasciculus. IFOF: Inferior frontooccipital fasciculus, MdLF: Middle longitudinal fasciculus, Unc Fasc: Uncinate fasciculus

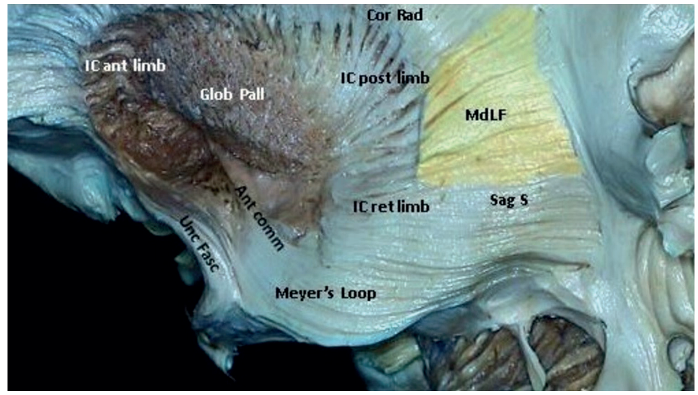

Figure 6. A close view focusing on the sagittal stratum. The posterior part of middle longitudinal fasciculus, anterior commissure, Meyer loop, and retrolenticular component of the internal capsule fibers intermingled and joined the sagittal stratum. The posterior part of middle longitudinal fasciculus is shown in yellow colour. Ant comm: Anterior commissure, AF: Arcuate fasciculus. Cor Rad: Corona radiata, Ext Caps: External capsule, Glob Pall: Globus pallidus, IFOF: Inferior frontooccipital fasciculus, IC ant limb: Internal capsule anterior limb, IC post limb: Internal capsule posterior limb IC ret limb: Internal capsule retrolenticular limb MdLF: Middle longitudinal fasciculus, Sag S: Sagittal stratum, Unc Fasc: Uncinate fasciculus

DISCUSSION

White matter pathways have been defined since the beginning of the twentieth century and most have been reviewed in detail with anatomical studies. While MdLF was first described in rhesus monkeys in 1984 (8), it was defined in humans by various tractography studies later (3,9). Maldonado et al. conducted the first fiber dissection study about MdLF in 2013 (10). But, the relationship of this pathway with neurocognitive features is still under investigation.

MdLF is an important cortico-cortical association fiber pathway. Diffusion tensor and tractography imaging revealed that MdLF originates from the temporal pole passes through the white matter in the STG and courses towards the dorsal of STG. MdLF extends from the upper part of the sagittal stratum and the lower part of the corona radiata caudally and reaches the IPL and superior parietal lobule. When examined by fiber dissection methods, it was seen that the posterior extension of MdLF is towards the upper parts of the lateral surface of the occipital cortex instead of the IPL (10). While passing through the sagittal stratum level, MdLF is located in the medial of the AF, in the superolateral of the IFOF and inferior longitudinal fasciculus (3). Both the sagittal stratum and MdLF cover the entire lateral wall of the atrium of the lateral ventricle (11). In particular, IFOF extends similarly to MdLF in the temporal lobe, and these two pathways should be distinguished. While IFOF advances medially in the deep white matter of the temporal lobe to the insula and external capsule, MdLF leaves the sagittal stratum laterally, and enters the temporal operculum (10).

MdLF consists of three parts as anterior, middle and posterior. The anterior part is located in the white matter of the temporal operculum. The middle part is located between the STG and the sagittal stratum. In this part, the fibers are denser and mingled. In the current literature, it has been reported that MdLF passes through the Heschl's gyrus fiber intersection area with AF, IFOF, optic and acoustic radiation (12). In our study, the intersection of the posterior of the Heschl gyrus and the middle part of the MdLF is clearly shown. The posterior part is the longest and widest part in the sagittal plane. In this part, the fibers are distributed in a narrow layer just medial to the AF (10).

MdLF is still investigating in terms of its functions. Considering the connection between the cortical areas whose functions are well known such as AG and STG, it can be claimed that MdLF has a role in language and attention functions (13,14). Since it provides a link between these two cortical structures, it is considered that MdLF plays roles in translating sounds and syllables into an articular form, processing words acoustically and phonetically and producing words (15). Some connections are reported to be transmitted through MdLF between AG and STG and the SPL which plays roles in determining the position of the objects and the body in space with the visuospatial perception (16). Also, some authors have suggested that MdLF represents a dorsal auditory pathway connected with the primary visual cortex and superior parietal lobule, and plays a role to assist in the spatial localization of sound (17,18). In experimental animal studies, it has been determined that the dorsal region of the temporal pole, where MdLF fibers courses, has a role in responding to both auditory and visual stimuli (6). In human studies, Molholm et al. reported that SPL is related to the integration of audiovisual information (19). Therefore, it can be considered that MdLF, which is located between SPL and temporal pole, may have a role in this function.

MdLF may be related to some clinical conditions, including various neurological and psychiatric disorders that arise from temporal pole, STG, AG, and SPL. These areas where MdLF fibers pass through are affected in some neurodegenerative diseases such as primary progressive aphasia, frontotemporal dementia, Alzheimer's disease, posterior cortical atrophy and corticobasal degeneration. Semantic dementia especially affects the temporal pole in the early stages of the disease (20,21). Also, some studies have been reported that anomalies occurring in the left STG, which is one of the regions where MdLF courses, cause schizophrenia and aphasic syndromes, and anomalies occurring in the right STG and AG cause attention deficit hyperactivity disorder (3,22,23). In addition, primary progressive aphasia may develop due to temporal pole and STG pathologies (24).

CONCLUSION

MdLF is a cortico-cortical association pathway located in the temporoparietal region of the brain, and associated with language, auditory, visual and cognitive functions. Because MdLF was defined later than other white matter fibers, a limited number of anatomical studies on MdLF have been conducted in the literature so far. Although anatomical dissection studies provide detailed information for approaches to structures adjacent to this pathway, collaborating the further tractography studies are needed.

Competing interests: The authors declare that they have no competing interest.

Financial Disclosure: There are no financial supports.

Ethical approval: This study was approved by the ethics committee of Bakirkoy Prof. Dr. Mazhar Osman Training and Research Hospital for Neurology, Neurosurgery and Psychiatry (08.01.2019/263).

REFERENCES

1. Schmahmann JD, Smith EE, Eichler FS, et al. Cerebral white matter: Neuroanatomy, clinical neurology, and neurobehavioral correlates. Ann N Y Acad Sci 2008;1142:266-309.
2. Wakana S, Jiang H, Nagae-Poetscher LM, et al. Fiber tract-based atlas of human white matter anatomy. Radiology 2004;230:77-87.
3. Makris N, Papadimitriou GM, Kaiser JR, et al. Delineation of the middle longitudinal fascicle in humans: a quantitative, in vivo, DT-MRI study. Cereb Cortex 2009;19:777-85.
4. Menjot de Champfleur N, Lima Maldonado I, Moritz-Gasser S, et al. Middle longitudinal fasciculus delineation within language pathways: A diffusion tensor imaging study in human. Eur J Radiol 2013;82:151-7.
5. Kalyvas A, Koutsarnakis C, Komaitis S, et al. Mapping the human middle longitudinal fasciculus through a focused anatomo-imaging study: shifting the paradigm of its segmentation and connectivity pattern. Brain Struct Funct 2020;225:85-119.
6. Poremba A, Saunders RC, Crane AM, et al. Functional mapping of the primate auditory system. Science 2003;299:568-72.
7. Conner AK, Briggs RG, Rahimi M, et al. A Connectomic Atlas of the Human Cerebrum-Chapter 12: Tractographic Description of the Middle Longitudinal Fasciculus, Oper Neurosurg 2018;15:429-35.
8. Seltzer B, Pandya DN. Further observations on parieto-temporal connections in the rhesus monkey. Exp Brain Res 1984;55:301-12.
9. Schmahmann JD, Pandya DN, Wang R, et al. Association fibre pathways of the brain: parallel observations from diffusion spectrum imaging and autoradiography. Brain 2007;130:630-53.
10. Maldonado IL, de Champfleur NM, Velut S, et al. Evidence of a middle longitudinal fasciculus in the human brain from fiber dissection. J Anat 2013;223:38-45.
11. Muftah Lahirish IA, Middlebrooks EH, Holanda VM, et al. Comparison Between Transcortical and Interhemispheric Approaches to the Atrium of Lateral Ventricle Using Combined White Matter Fiber Dissections and Magnetic Resonance Tractography. World Neurosurg 2020;138:478-85.

12. Fernández L, Velásquez C, García Porrero JA, et al. Heschl's gyrus fiber intersection area: a new insight on the connectivity of the auditory-language hub. Neurosurg Focus 2020;48:7.
13. Makris N, Pandya DN. The extreme capsule in humans and rethinking of the language circuitry. Brain Struct Funct 2009;213:343-58.
14. Makris N, Preti MG, Asami T, et al. Human middle longitudinal fascicle: variations in patterns of anatomical connections. Brain Struct Funct 2013;218:951-68.
15. Hickok G, Poeppel D. The cortical organization of speech processing. Nat Rev Neurosci 2007;8:393-402.
16. Heilman KM, Van Den Abell T. Right hemisphere dominance for attention: the mechanism underlying hemispheric asymmetries of inattention (neglect). Neurology 1980;30:327-30.
17. Palejwala AH, O'Connor KP, Pelargos P, et al. Anatomy and white matter connections of the lateral occipital cortex. Surg Radiol Anat 2020;42:315-28.
18. De Witt Hamer PC, Moritz-Gasser S, Gatignol P, et al. Is the human left middle longitudinal fascicle essential for language? A brain electrostimulation study. Hum Brain Mapp 2011;32:962-73.
19. Molholm S, Sehatpour P, Mehta AD, et al. Audio-visual multisensory integration in superior parietal lobule revealed by human intracranial recordings. J Neurophysiol 2006;96:721-9.
20. Galton CJ, Patterson K, Graham K, et al. Differing patterns of temporal atrophy in Alzheimer's disease and semantic dementia. Neurology 2001;57:216-25.
21. Luo C, Makaretz S, Stepanovic M, et al. Middle longitudinal fascicle is associated with semantic processing deficits in primary progressive aphasia. Neuroimage Clin 2020;25:102115.
22. Rajarethinam R, Sahni S, Rosenberg DR, et al. Reduced superior temporal gyrus volume in young offspring of patients with schizophrenia. Am J Psychiatry 2004;161:1121-4.
23. Asami T, Saito Y, Whitford TJ, et al. Abnormalities of middle longitudinal fascicle and disorganization in patients with schizophrenia. Schizophr Res 2013;143:253-9.
24. Sapolsky D, Bakkour A, Negreira A, et al. Cortical neuroanatomic correlates of symptom severity in primary progressive aphasia. Neurology 2010;75:358-66.