Cerrahpaşa Med J 2020; 44(3): 125-132 **ORIGINAL ARTICLE / ÖZGÜN ARAŞTIRMA**

Microsurgical Feasibility, Boundaries, and Anatomical Landmarks in Anterior Temporal Lobectomy: A Novel Cadaveric Study

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Abstract

Objective: This study aimed to evaluate the microsurgical anatomy of the fiber tract connections of the anterior temporal lobe and examine its potential functional role. Anterior temporal lobectomy (ATL) with dissection of the fiber tracts and amygdalohippocampectomy in surgical process to the mesial temporal lobe were performed.

Methods: In total, 4 formalin-fixed human brains (8 sides) were dissected by the Klingler technique in a stepwise manner from the lateral to medial under 6x–40x magnification using a surgical microscope. All pictures of the dissection were obtained using 3-dimensional photographic method.

Results: The trajectories and connections of these fibers, in particular the travel in the surgical corridor, were demonstrated with correlation to the surgery. According to our anatomical study, important landmarks, such as crossing of the fibers, eloquent areas of the temporal lobe, and the white matter pathways, related to the transcortical amygdalohippocampectomy technique using ATL were defined.

Conclusion: The temporal lobe is one of the most complex part of the brain and has numerous connections that must be preserved in the transtemporal approach. Better understanding of these fiber tracts in the preoperative stage is important for preventing the brain damage in the visual and language processes.

Keywords: Anterior temporal lobe, microsurgical anatomy, white matter, fiber dissection, fiber tracts

Anterior Temporal Lobektominin Mikrocerrahi Açıdan Uygulanabilirliği, Sınırları ve Anatomik Belirteçler: Güncel Kadavra Çalışması

Öz

Amaç: Bu çalışmanın amacı, anterior temporal lobun lif yolu bağlantılarının mikrocerrahi anatomisini değerlendirmek ve potansiyel fonksiyonel rollerini incelemektir. Mesial temporal loba yönelik cerrahi işlemde, lif yolaklarının diseksiyonu ile anterior temporal lobektomi ve amigdalohippokampektomi gerçekleştirildi.

Yöntemler: Dört formalinle fikse edilmiş insan beyni (8 taraf), cerrahi mikroskop kullanılarak 6-40x büyütme altında kademeli olarak lateralden mediale doğru Klingler tekniği ile diseke edildi. Diseksiyonun tüm resimleri 3D fotografik yöntem kullanılarak elde edildi.

Bulgular: Bu liflerin yörüngeleri ve bağlantıları, özellikle cerrahi koridoriçindeki seyirleri, cerrahinin korelasyon gözetilerek gösterilmiştir. Anatomik çalışmamıza dayanarak, temporal lobdaki önemli landmarklar, liflerin çaprazlamaları ve temporal lobun kritik önemdeki alanları ve anterior temporal lobektomi yapılarak gerçekleştirilen transkortikal amigdalohippokampektomi tekniği ile ilişkili beyaz cevher yolakları tanımlandı.

Sonuçlar: Temporal lob beynin en karmaşık kısımlarından biridir ve transtemporal yaklaşımlarda korunması gereken çok sayıda bağlantıya sahiptir. Ameliyat öncesi aşamada bu lif izlerinin daha iyi anatomik bilinmesi, görsel ve dil işlemede bozukluklar gibi beyin hasarını önlemek için önemlidir.

Anahtar Kelimeler: Anterior temporal lob, mikrocerrahi anatomi, beyaz cevher, fiber diseksiyonu, fiber yolakları

The temporal lobe has 2 surfaces, the large lateral and basal. The medial surface is the most complex of the medial cortical areas. It is limited by some structures and is formed predominantly by the rounded medial surfaces of the parahippocampal gyrus (PHG) and uncus (U). The lateral surface is dorsally separated from the frontal and anterior parietal lobes by the lateral sulcus and more caudally from the posterior parietal lobe [1-4]. The anterior occipital sulcus limits the temporal lobe caudally on the lateral surface, and the occipitotemporal sulcus is the border for the temporal lobe on the basal side. Ventromedially, the limbic lobe

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by the collateral and rhinal sulci form a border with the temporal lobe [1-3].

Aneurysms of the middle cerebral artery (MCA), arteriovenous and cavernous malformations, malignant and benign brain tumors, intracerebral hematomas, and in particular epileptic lesions can be the potential targets for the temporal lobe surgery [5]. Temporal lobectomies have been described and performed in 1936 to treat epilepsy [6, 7]. Resection of the brain tumors have been reported as early as the 1990s [6, 8, 9]. Disconnecting the temporal lobe can seem trivial, but these procedures have several pitfalls. The dominant temporal lobe must be carefully resected because these surgeries may be performed awake to adequately map the language center [6]. In the literature, different surgical techniques have been recommended for temporal lobe epilepsy. Anterior temporal lobectomy (ATL) has been the primary and popular suggested approach. ATL is also called 2/3 standard temporal lobectomy [7].

In the literature, there are some suggestions about the dissection of ATL. In a study, the posterior extent of resection was described as 4.5 cm in the dominant temporal lobe and 5.5 cm in the nondominant one in the ATL procedure [10-12]. Individual dissection of the medial [collateral sulcus (CS), temporal horn (TH), crural and ambient cisterns, and lateral (sylvian) fissure, (SF)] divisions of the temporal lobe was described. Removing the lateral neocortex and part of the fusiform gyrus parallel to the SF represents the first step [10-12]. The TH forms the medial edge in the coronal plane. Second, the amygdaloid body (AmB), U, fimbriae, hippocampus (H), and collateral eminence should be identified and if necessary, must be resected with the PHG to complete the procedure. The surgeons must have advanced anatomical knowledge of the fiber tract to minimize the brain damage [10, 11] because the anterior temporal lobe plays a critical role in semantic memory, such as knowledge of objects, people, words, and facts [13].

ATL is associated with several important fiber tracts [inferior longitudinal fascicle (ILF), optic radiation (OR), uncinate fascicle (UF), middle longitudinal fascicle (MdLF), arcuate fasciculus (AF) and inferior fronto-occipital fasciculus (IFOF), anterior commissure (AC)] and neural structures [H, PHG, occipitotemporal gyrus (OTG), TH, U, limen insula (Li), superior temporal gyrus (STG), inferior temporal gyrus (ITG), and medial temporal gyrus (MTG),and AmB] that are revealed by performing a stepwise dissection. As other studies show, surgical procedures on the anterior temporal lobe have different repercussions on the subcortical white matter tract anatomy [4, 5, 14, 15]. The microsurgical anatomy of the anterior temporal lobe is one of the most complex anatomies and not yet well identified. This region contains several important fiber tracts that need to be uniquely described [14].

The purpose of this research is to study the anatomy of the anterior temporal lobe to determine the surgical boundaries and crucial points of the ATL.

Material and Methods

In total, 4 formalin-fixed human brains (8 sides) were frozen at –16°C for at least 2 weeks to separate the tracts and facilitate dissection. After freezing the specimens, they were thawed and dissected under 6x to 40x magnifications provided by a Zeiss surgical microscope (Carl Zeiss AG, Germany) with surgical dissectors of different tip widths. Gentle removal of the surface vascular structures, dura, pia, and arachnoid mater was the first step of the preparation process. Between the dissection periods, the specimens were kept in a 10% formaldehyde solution. The hemispheres were dissected in a systematic and stepwise manner, from lateral to medial, using the fiber dissection technique and the microscope until the medial wall of the brainstem was revealed. All the stages of the dissection were recorded photographically with a Canon EOS 550 digital camera (Canon, Tokyo, Japan) for step-by-step demonstration. The microsurgical fiber tract anatomy of the anterior temporal lobe and its relationship with the surrounding structures were investigated.

Results

Temporal lobe anatomy

The temporal lobe has 4 surfaces; superior, inferior, lateral, and medial. The lateral parietotemporal line separates the temporal lobe from the occipital lobe, and the temporo-occipital line separates it from the parietal lobe. Superior, middle, and inferior temporal gyri are located parallel on the lateral surface. The superior temporal sulcus is located between the superior and middle temporal gyri, and the inferior temporal sulcus is located between the middle and inferior temporal gyri. The superior surface overlooking the SF is called the "opercular surface." It has 3 parts from posterior to anterior direction; planum polare, Heschl's gyrus, and planum temporal. It runs superiorly deep between the frontal and parietal lobes and is inferiorly located between the temporal lobe and the opercular surface and merges with the SF at the insula level (Figure 1). The inferior surface of the temporal lobe is formed by 3 gyri from lateral to medial, the inferior surface of the ITG, fusiform gyrus, and PHG. The occipitotemporal sulcus is located between the ITG and the fusiform gyrus and between the PHG and the fusiform gyrus; the rinal sulcus is located behind the CS. The anterior part begins from

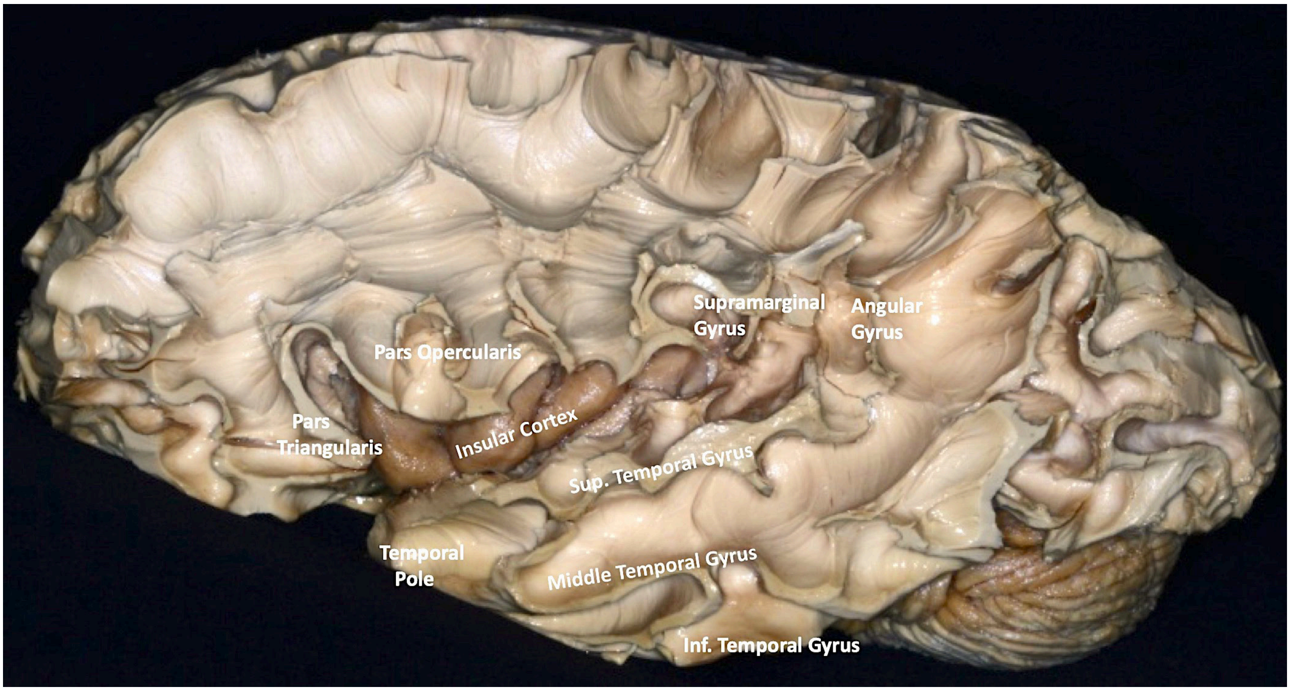

Figure 1. Lateral view of the left hemisphere. Dissection is continued after removal of the short association fibers of frontal, occipital and in particular temporal. Superior, inferior and middle temporal gyri are observed

the anterior border of the rinal sulcus and U and ends at the posterior border of the U. The middle part ends in the quadrigeminal plate on the posterior brainstem. The posterior part ends at the calcarine point where the parieto-occipital and calcarine sulcus meet. We focused on its anterior part; the anterior part of the medial surface of the temporal lobe is formed mainly by the U. The U has anterior and posterior parts that merge into the apex. The anterior part of the U that contains the AmB is adjacent to the "anterior perforated substance" in the superomedial direction, the entry point of the perforating arteries originating from the anterior circulating arteries. The posterior part of the U is divided into 2 as superior and inferior. The anterior part of the U is adjacent to the carotid cistern, which includes the internal carotid artery and the proximal part of the MCA; the apex of the U is adjacent to the 3rd cranial nerve. The posterior part of the U is adjacent to the crural cistern and crus cerebri containing the posterior cerebral artery. The head of the His located in the posterior part of the U, which is a medial surface structure, and as such, it is located in the anterior of the inferior choroidal point. There is no obvious anatomical border between the trunk and tail sections of the H. The AmB, located in the anterior part of the U, separates from the H by the uncal recess and forms the anteromedial wall of the TH.

ATL including amygdalohippocampectomy

ATL was first described by Penfield and Baldwin in 1952 [9]. The lateral process includes the SF and nearly 4.5 cm dominant and 5.5 cm nondominant hemispheres resection. The medial process is described as lateral amygdalectomy, hippocampectomy, and U resection [10]. The neocortical removal begins at the STG. First, we visualized the Li and anterior temporal lobe (Figure 2). The dissection was directed perpendicularly to the SF and toward the base of the middle fossa. The TH served as the landmark for neocortical removal, the resection above and lateral to the TH was performed, and it was removed superiorly and laterally (Figures 3a and b). Careful sharp dissection is mandatory for preserving the vascular structures to avoid congestive complications. Next, ATL was performed until the U, providing a sufficient anteroposterior corridor to resect the mesial region. The surgical preparation for ATL included exposing the U using subpial dissection and revealing the inferior temporal stem and lateralizing the related structures after U resection. U is in the neighborhood of the brainstem. Therefore, the subpial aspiration of the anterior portion of the U should be softly dissected. The anterior wall of the TH of the lateral ventricle is formed by AmB and is removed partially and laterally. The anterior segment of U has a close relationship with the AmB and internal cerebral artery, and the proximal main trunk of the MCA can be exposed after removal of anterior segment of the U. The crural cistern can be observed after opening the choroidal fissure. While opening the choroidal fissure, beginning at the inferior choroidal point anteriorly is the crucial and first step of the hippocampectomy. This

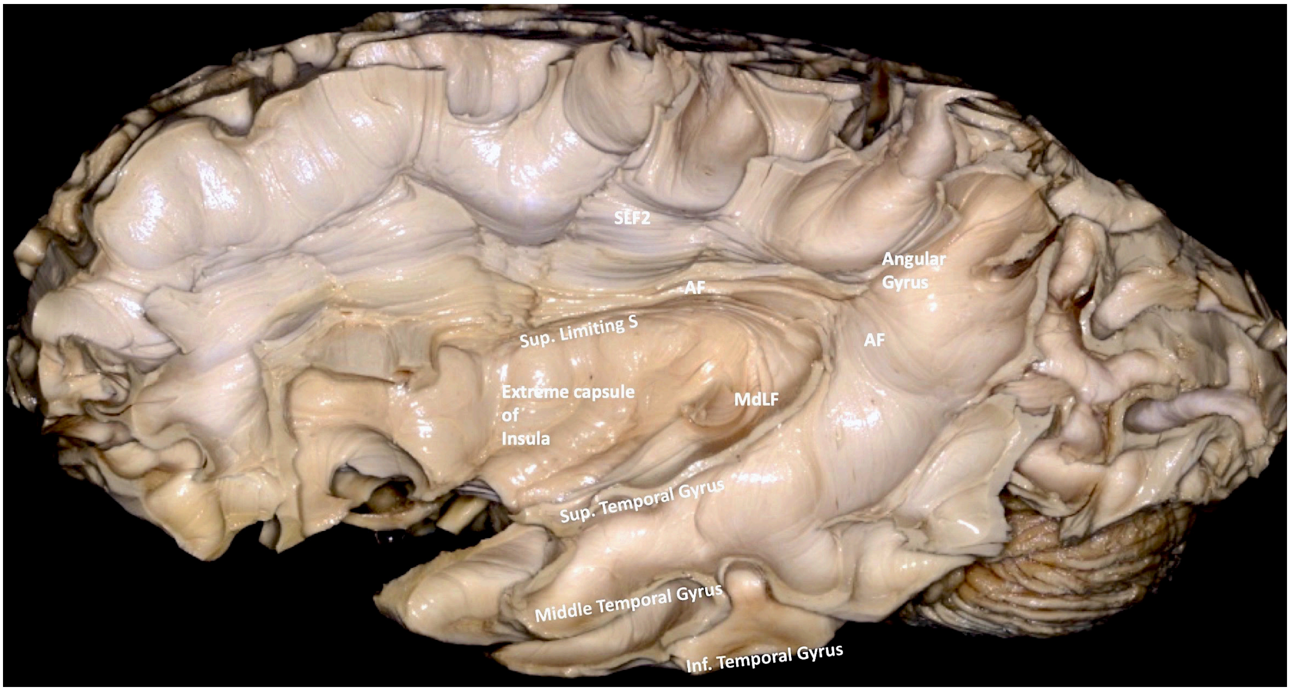

Figure 2. Dissection is continued to expose the deep fiber tracts of the temporal lobe. Supramarginal, angular, superior, inferior and middle temporal gyri, temporal pole have been exposed. AF is observed below the supramarginal gyrus. More decortication provides a visualization for MdLF, ILF. Reaching to the extreme capsule can be performed by step by step dissection of insula. Also, the insula and its surface were decorticated to reveal the extreme capsule fibers that interconnect adjacent insular gyri and the operculum

targeted region can be exposed between the collateral eminence laterally and choroidal fissure medially. Hippocampectomy is the final step of the subpial resection with preserving the lateral geniculate body (LGB) that is a part of the visual system.

Anatomic evaluation of the fiber dissection

The fiber dissection correlating to the ATL was performed from lateral to medial. Removing the arachnoid membrane exposed the superficial anatomy of the temporal lobe. The veins and arteries usually are preserved and when necessary, are sacrificed only in the last stage. The sulco-gyral anatomy of each specimen was carefully dissected with special attention given to the topographic aspect of the temporal lobe. A wooden dissector and aspirator were used to remove the gray matter. After removing the cortical gray matter surrounding the anterior temporal lobe on the lateral surface, we continued to the deep sulcus area, and the subcortex was posed as a thinner layer. Next, the dissection was extended from the lateral gyral surface to the brainstem. We continued to the operculum 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 was preserved because the fascicle fibers can be damaged easily. White matter of the opercular area was removed with sharp dissection to expose the anterior temporal lobe. Stepwise dissection revealed the deep fiber tracts, such as OR, ILF, AF, and MdLF, more clearly. We identified the related fiber tracts to the ATL process (Figures 2 and 3).

ATL can cause visual deficits and memory problems. Therefore, a clear understanding of the anatomical pathways is critical during this process. The temporal stem is located in the superior surface of the temporal lobe and under the inferior limiting sulcus cortex. It is a bridge to the temporal lobe white matter and connects to the basal ganglia, insula, and frontal lobe. When the cortex of the superior surface is removed, first the fibers of the external and extreme capsule are observed. Extreme capsule fibers start from the opercular areas, pass under the insula, and extend into the operculum. Anatomical dissections have shown that these connections are predominantly present between inferior frontal gyrus (IFG) and the temporal pole STG. The UF consists of anteriorly located fibers of the external capsule that pass through the temporal stem. Removal of the cortical surface of the Li allows the visualization of the UF as known at the lateral edge of the anterior perforated substance bordering the antero-inferior part of the insula. The anterior part of the frontotemporal transition is called the UF and connects the fronto-orbital region to the temporal pole. Ventral claustrum is located under the UF fibers and has several gray matter masses. Continuing the dissection reaches the external

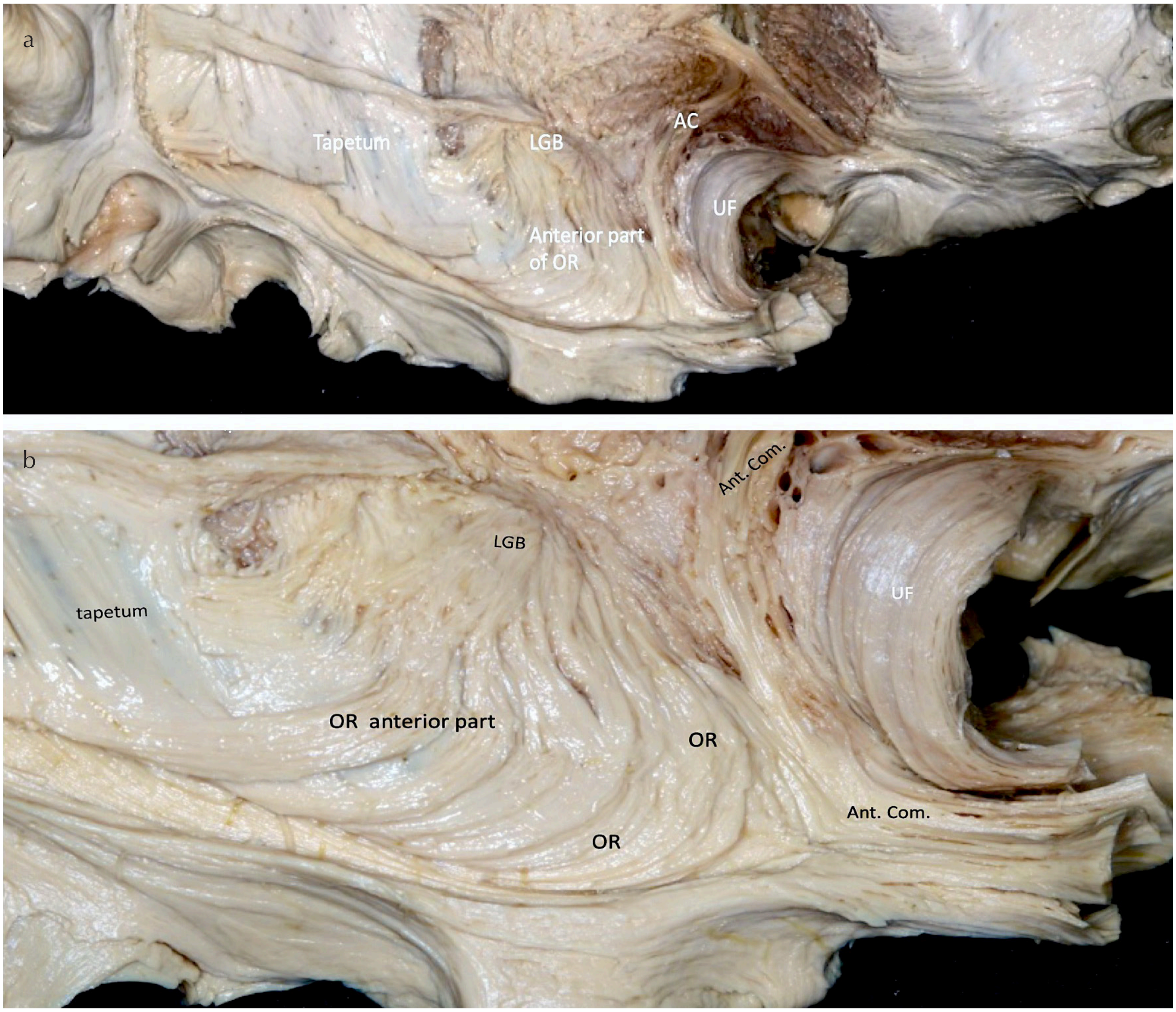

Figure 3. a, b. Lateral view. The removal of the AF and ILF expose the optic radiation and AC. UF looks like a hook-shaped bundle and is located between the inferior frontal gyrus and the lower surfaces of the frontal lobe (a). The closer lateral view of the anterior part of OR before the removal of the anterior part of OF to reveal the hippocampus, amygdala, hippocampus and fimbria, choroidal fissure (b)

capsule that connects the frontomesial and the temporomesial regions. After this stage in the dissection, the AmB is exposed inferiorly and medially to the UF. The UF rotates around the inferior area of the Li and provides a connection between the anterior part of the temporal pole and the lateral temporal cortex and the orbitofrontal cortex (Figure 3). It also includes some of the fibers of the external capsule that pass through the temporal stem. Optic fibers that are seen when the lateral ILF and superior UF are removed have a complex anatomy. Removing of the U-shaped fibers under the gray of the temporal lobe exposes the inferior longitudinal fasciculus. This fascicle has a connection that plays a critical role in visual memory between the occipital lobe and the anterior temporal lobe. Anatomical dissection showed that it has a structure that is a coalescence of different short fibers. Mediolateral dissection of the ependymal layer that covers the walls of the ventricles highlights the tapetum or the callosal radiations, which separate the sagittal stratum [5, 16]. ILF travels along the lateral wall of the TH lateral to the optical fibers and at the base of the TH. It connects the anterior part of the temporal lobe to the fusiform gyrus and the dorsolateral part of the occipital lobe. AC fibers that course from the medial to lateral have a contact ventrally to the lentiform nucleus. Carrying the impulses from the superior visual quadrant is a part of the anterior bundle running anteriorly above the TH. It also forms an anterior bend called the Meyer's loop. The LGB of the thalamus is the origin point of the OR and has 3 parts; anterior, central, posterior. The ILF runs adjacent to the anterior part of the OR coursing.

The OR is dissected deeper than the MTG behind the UF and courses straight to the occipital side after its anterior part over the TH of the lateral ventricle (Figure 3a). The temporal portion of the OR is supplied by the anterior choroidal artery and other MCA branches within the SF, including the lenticulostriate and inferior temporo-occipital artery [15, 17, 18]. Our dissection exposed the parts of the OR related to the anterior temporal lobe.

The AF is a broad white matter tract surrounding the insula and connects with the frontal, parietal, and temporal cortices in their depth [14]. The component of the AF bundle connects the posterior-superior temporal region to the IFG. This bundle passes the Wernicke's region dorsally and travels around the posterior part of the lateral sulcus. Next, traveling rostrally to the supramarginal and somatosensory areas in the parietal operculum, it reaches the Broca's region. The superficial part of the AF was observed vertically after dissecting the posterior-inferior part of the SF (Figure 2). The AF runs horizontal to the SF and anteriorly courses the IFG via the supramarginal gyrus passing the angular gyrus (AG) of the posterior part to reach the IFG. IFOF is one of the most important fiber tracts associated with semantic language processing and goal-oriented behavior [19]. IFOF is in the depth of the temporal lobe and insula and was one of the first major associations, which is a fiber pathway to be described in the human brain. It connects the occipital cortex, temporobasal areas, and superior parietal lobe to the frontal lobe. SLF, AF, ILF, and MdLF have a close relationship with IFOF. Moreover, IFOF crossing with other tracts has been dissected [16, 19, 20]. The anterior third of the superior limiting sulcus and superior half of the anterior limiting sulcus cover the IFOF, and IFOF courses the UF as a small course at the level of the Li. IFOF runs in the superior and middle temporal gyri deeper than the middle third of the inferior limiting sulcus. Heschl's gyrus decortication is the first step to reveal the MdLF. Our dissection exposed a white matter pathway extending from the anterior of the STG toward the AG and long direct segment of the superomedial arcuate fascicle (LDSAF). MdLF is associated with a connection between the anterior temporal region and AG via Heschl's gyrus. Although almost all MdLF fibers passed through the medial of LDSAF, the cortical MdLF fibers coursed the LDSAF laterally. The end point of the MdLF was located more superior and lateral than the deep IFOF and was detected in a close relationship with AG (Figure 2). The anterior part of the MdLF from the temporal pole to the posterior insular point courses superior to the TH [4, 5, 18].

Discussion

Temporal lobe epilepsy is usually refractory to clinical treatment and is one of the most common form of epilepsy in adults. Various lobectomies, in particular temporal lobectomy, were reported by many researchers but were first described by Falconer and Taylor in 1963 [21, 22]. ATL is the most popular and has been found to be the most effective method. Widespread use of this method can be explained by the experience in the temporal lobe surgery and good visualization of the anterior temporal lobe fiber tracts after decortication [21, 22]. The anterior temporal lobe has important subcortical structures, especially white matter fibers, which play a role in visual information. Better understanding of this region provides some advantages for microsurgical practice depending on fiber dissection techniques to treat epilepsy and other pathologies, such as vascular lesions and benign or malignant tumors. The dissections performed with a surgical perspective decrease the surgical orientation for this region and add a successful surgical approach for treatment with no deficit [10, 23-25]. Lateral approaches, inferior approaches, and trans-sylvian approaches were identified in the literature as surgical methods for the temporal lobe epilepsy from a neuro-anatomical perspective. ATL and the transcortical selective amygdalohippocampectomy were evaluated in the lateral groups [26, 27]. In this study, we focused on these approaches and aimed to present anatomical data according to the natural coursing of the fiber tracts for avoiding surgical complications, especially visual field defects.

According to the standard ATL, resection should be in the order and the UF, IFOF, OR, temporal segment of the AC, and ILF fornix must be carefully separated as we described in our fiber dissection. Epilepsy is a network disease and is usually related to the temporal lobe [28]. Complex fiber bundles associated with the anterior temporal lobe probably determine the success of the surgery, and their damage could cause a functional deficit during the surgery. In our study, we checked the direction of the fiber tracts and the relationship with deep white matter structures that is important in ATL surgery. OR should be individualized from the temporal pole in each hemisphere for ATL to reveal the anatomic differences and conduct a safe and accurate procedure [28, 29]. We believe that the approach with individualizing the ATL can be useful in achieving the best surgical outcome for patients.

IFOF, MdLF, AF, OR, UF, and ILF should be dissected in the ATL. The ventral segment of AF has a function in phonological language processing, whereas the dorsal segment of AF has a role in lexical and semantic language processing. The IFOF has multiple connections between the ipsilateral, frontal, occipital, posterior parietal, and temporal lobes; high neurocognitive functions, such as picture naming, object recognition, naming of sounds, and recognition of speech are associated with IFOF. Therefore, neurocognitive defect and sensorial dysphasia can appear with IFOF damage [16, 29]. The UF is a bridge between the frontal and temporal lobes, and there is a strong evidence about the association between UF and auditory, verbal, and declarative memory. The ILF travels between the ipsilateral, temporal, and occipital lobes and plays a role in visual emotion and visual memory. Damage to the OR fibers can cause contralateral quadrantanopia. Meyer's loop is an anterior part of the OR and is located approximately 3 cm posterior to the temporal pole. This is an important anatomical landmark to preserve the visual system during the surgery [16, 29, 30].

In conclusion, the information and relationship between different white matter networks and their role in different types of epilepsies are still controversial. ATL is a feasible approach in epilepsy surgery and is mainly based on anatomical principles to preserve the fiber tracts related to the temporal lobe. Despite technological developments in neuroimaging, better anatomical and functional understanding of this region is critical for achieving good results with no deficits. Important subcortical structures, especially the white fibers that are responsible for visual information, must be dissected carefully in ATL for a safe and accurate surgery.

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Informed Consent: N/A

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