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Neuroanatomical study

Transcortical selective amygdalohippocampectomy technique through the middle temporal gyrus revisited: An anatomical study laboratory investigation

Baran Bozkurt [a,*], Ricardo da Silva Centeno [b], Feres Chaddad-Neto [b], Marcos Devanir Silva da Costa [b], Marcelo Augusto Acosta Goiri [b], Ali Karadag [a], Bekir Tugcu [c], Talat Cem Ovalioglu [c], Necmettin Tanriover [d], Serdar Kaya [e], Kaan Yagmurlu [f], Andrew Grande [a]

[a] *Department of Neurosurgery, University of Minnesota, Mayo Building, 4th floor 420 Deliware St., SE Minneapolis, MN 55455, USA*
[b] *Department of Neurosurgery, Federal University of Sao Paulo, Sao Paulo, Brazil*
[c] *Department of Neurosurgery, Bakirkoy Research and Training Hospital for Neurology, Neurosurgery, and Psychiatry, Istanbul, Turkey*
[d] *Department of Neurosurgery, Cerrahpasa Medical School, University of Istanbul, Istanbul, Turkey*
[e] *Department of Otolaryngology, University of Minnesota, Minneapolis, MN, USA*
[f] *Department of Neurosurgery, Barrow Neurological Institute, St. Joseph's Hospital and Medical Center, Phoenix, AZ, USA*

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ABSTRACT

The anterior temporal lobectomy (ATL) and selective amygdalohippocampectomy (SelAH) have been used for surgical treatment of mesial temporal lobe epilepsy. We examined the comprehensive white matter tract anatomy of the temporal lobe to gain an insight into the trans-middle temporal gyrus, a lateral approach which has been commonly used. The transmiddle temporal gyrus approach was performed in a stepwise manner on cadaveric human heads to examine the traversing white matter pathways through it and the structures located in the temporal horn. We reviewed the literature to compare the trans-middle temporal gyrus approach with other SelAH techniques based on surgical outcomes. There does not appear to be a significant difference in seizure outcome between SelAH and ATL. However, the SelAH provides a better neuropsychological outcomes than the ATL in selected patients. Each SelAH approach has individual advantages and disadvantages. Based on our anatomical study, in the transcortical amygdalohippocampectomy technique through the middle temporal gyrus the white matter pathways to be encountered. In the temporal horn, the collateral eminence, hippocampus, lateral ventricular sulcus, choroidal fissure, inferior choroidal point, choroid plexus, fimbria of the fornix, and amygdala are exposed. The subpial dissection is performed along the lateral ventricular sulcus from the collateral eminence on lateral side and from the choroidal fissure on medial side by microdissector for *en bloc* resection of the hippocampus proper. The trans-middle temporal gyrus approach is commonly used in treatment of mesial temporal lobe epilepsy patients. A better anatomical and functional understanding of the structures of the temporal lobe is crucial for safer and more accurate surgery.

1. Introduction

One-third of epilepsy patients are living with medically refractory epilepsy due to hipoocampal sclerosis. Multiple studies have demonstrated that epilepsy surgery has more successful outcomes than medical treatments on appropriately selected patients [1]. The most critical issue in temporal lobe surgery is the removal of epileptogenic focus without causing any new neurological deficit on patient.

The anterior temporal lobectomy (ATL) has been described first for treatment of the epilepsy patients. With advent of the neuroimaging technology led to devise the selective amygdalohippocampectomy techniques for treatment of mesial temporal lobe epilepsy (MTLE) patients. The surgical approaches for selective amygdalohippocampectomy (SelAH) has been classified as an anterior, which is the transsylvian, a lateral, which is the transcortical and subtemporal, and a posterior [2], which is the posterior interhemispheric and the paramedian supracerebellar infratentorial [3,4]. The lateral transcortical approach has been described by Paulo Niemeyer in 1958 as an alternative to the classical ATL method has still been widely used [5–7]. Later, a trajectory through

* Corresponding author. Tel.: +1 16123239929; fax: +1 16126240644.
E-mail address: bbozkurt@umn.edu (B. Bozkurt).

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the superior temporal gyrus has been described as the transcortical approach [8].

Herein, we revisited the trans-middle temporal gyrus approach to evaluate its surgical technique with the internal anatomy of the temporal lobe. We also compared the trans-middle temporal gyrus approach with other SelAH and ATL approaches based on clinical data obtained from literature and neurofunctional anatomy of the white matter pathways of the temporal lobe to relate between surgical outcomes and these approaches. To best of our knowledge, this study is the most comprehensive combination of the surgical technique with the temporal lobe white matter anatomy in trans-middle temporal gyrus approach.

2. Materials and methods

2.1. Anatomical study

Three formalin-fixed and silicone injected human heads were examined. The heads were frozen to perform the fiber dissection technique at −16 °C for 2 weeks [9,10]. The heads were positioned using Mayfield head holders in a manner that replicate the actual surgical setting. The trans-middle temporal gyrus approach was performed in a stepwise manner. Each structure from skin to temporal horn of the lateral ventricle including gray matter, white matter and vessels were exposed under ×6 to ×40 magnifications using Leica surgical microscope (Leica Microsystems, Wetzlar, Germany). Photographs were obtained with E CANON EOS 550 D (Canon Inc., Ohta-ku, Tokyo, Japan) of all dissection stages.

2.2. Clinical study

A comprehensive clinical examination and preoperative tests, which are magnetic resonance imaging (MRI), electroencephalography (EEG), long-term EEG-video monitoring to obtain electrophysiological data, computer tomography, and neuropsychological assessment were applied to all patients. The surgical procedures were performed under general anesthesia. Preoperative, intraoperative and postoperative images were obtained from a selected patient. We also notes the affected fiber tracts of the temporal lobe according to amygdalohippocampectomy procedures in Table 1.

3. Results

3.1. Anatomical study

The lateral temporal surface has three gyri and two sulci; the superior, middle and inferior gyri and superior and inferior sulci. The vascular structures to be encountered on the surface are the vein of Labbe and the cortical branches of the middle cerebral artery (Fig. 2A). The vein of Labbe on lateral surface connects the superficial sylvian and middle temporal veins to the transverse sinus, and this vein should be preserved [11]. The blood supply of the temporal lobe is provided by the temporopolar, anterior, middle, and posterior temporal areas [12], which are the branches of middle cerebral and posterior cerebral arteries.

After passing through the middle temporal gyrus, the short association fibers, which interconnect neighbor gyri, are encountered first (Fig. 2B). The fibers located deeper to the short association fibers are the long association fibers, which interconnect distant areas in the same hemisphere [9]. The first long association fiber tract to be encountered in middle temporal gyrus is the arcuate fasciculus (AF) (Fig. 2C). The AF has a ventral and a dorsal segments [13]. The AF ventral segment in the middle one third of the middle temporal gyrus, and the AF dorsal segment in the posterior one third of the middle temporal gyrus are situated. Progressingly deeper to the AF, the inferior fronto-occipital fasciculus (IFOF) is encountered. The IFOF and the occipital extension of the anterior commissure, which is situated a deeper to the IFOF, travels through the superior and middle temporal gyri. Finally, the optic radiation fibers in the superior and middle temporal gyri and then tapetal fibers in the lateral wall of the temporal horn of the lateral ventricle are encountered before entering into the temporal horn of the lateral ventricle (Fig. 2D, E). After opening the ependymal layer of the lateral wall of the temporal horn of the lateral ventricle, the collateral eminence, hippocampus, lateral ventricular sulcus, choroidal fissure, inferior choroidal point, choroid plexus, fimbria of the fornix, and amygdala are exposed (Fig. 3A, B). *The collateral eminence* situated lateral to the hippocampus covers the base of the temporal horn of the lateral ventricle. The collateral eminence is the indentation of the collateral sulcus and the most medial area for neocortical removal. *The hippocampus* can be easily identified between the collateral eminence laterally and choroidal fissure medially. *The lateral ventricular sulcus* separates the hippocampus proper from the collateral eminence, extending anteriorly toward the amygdala–hippocampal junction. The hippocampus sits over the parahippocampal gyrus and has the head, body and tail parts. The anterior portion of the hippocampal head blends into the amygdala. The medial border of the hippocampus is *the choroidal fissure*, and the inferior choroidal point is the at the most anterior and inferior point of the choroidal fissure. *The inferior choroidal point* is situated medial to the head of hippocampus and posterior to the uncus. The anterior choroidal artery passes through the inferior choroidal point to enter into the temporal horn of the lateral ventricle (Fig. 3B, C). The opening of the choroidal fissure exposes the crural and ambient cisterns (Fig. 3D). *The fimbria of the fornix* located just medial to and above the dentate gyrus covers medial

Table 1
Comparison of damaged structures in surgical techniques

Structure of interest	Anterior temporal lobectomy	Transsylvian amygdalohippocampectomy	Transcortical through middle temporal gyrus SelAH
IFOF	+Neurocognitive defects (picture naming, object recognition, naming of sounds and recognition of speech) [15,16]	+Neurocognitive defects(picture naming, object recognition, naming of sounds and recognition of speech) [15,16]	+Neurocognitive defects (picture naming, object recognition, naming of sounds and recognition of speech) [15,16]
ILF	+Object identification and recognition, language [9]	–	–
MLF	+Language and attention disorders [9]	–	–
Uncinate fasciculus	+Neurocognitive defects (recognizing faces, actions, objects and emotion) [17,18]	+Neurocognitive defects (recognizing faces, actions, objects and emotion) [17,18]	–
Optic radiation	–	+Upper contralateral quadrantanopia [20,21]	+Upper contralateral quadrantanopia [20,21]
Arteries	–	+Vassospasm [50]	–

IFOF = inferior fronto-occipital fasciculus, ILF = inferior longitudinal fasciculus, MLF = middle longitudinal fasciculus, SelAH = selective amygdalohippocampectomy.

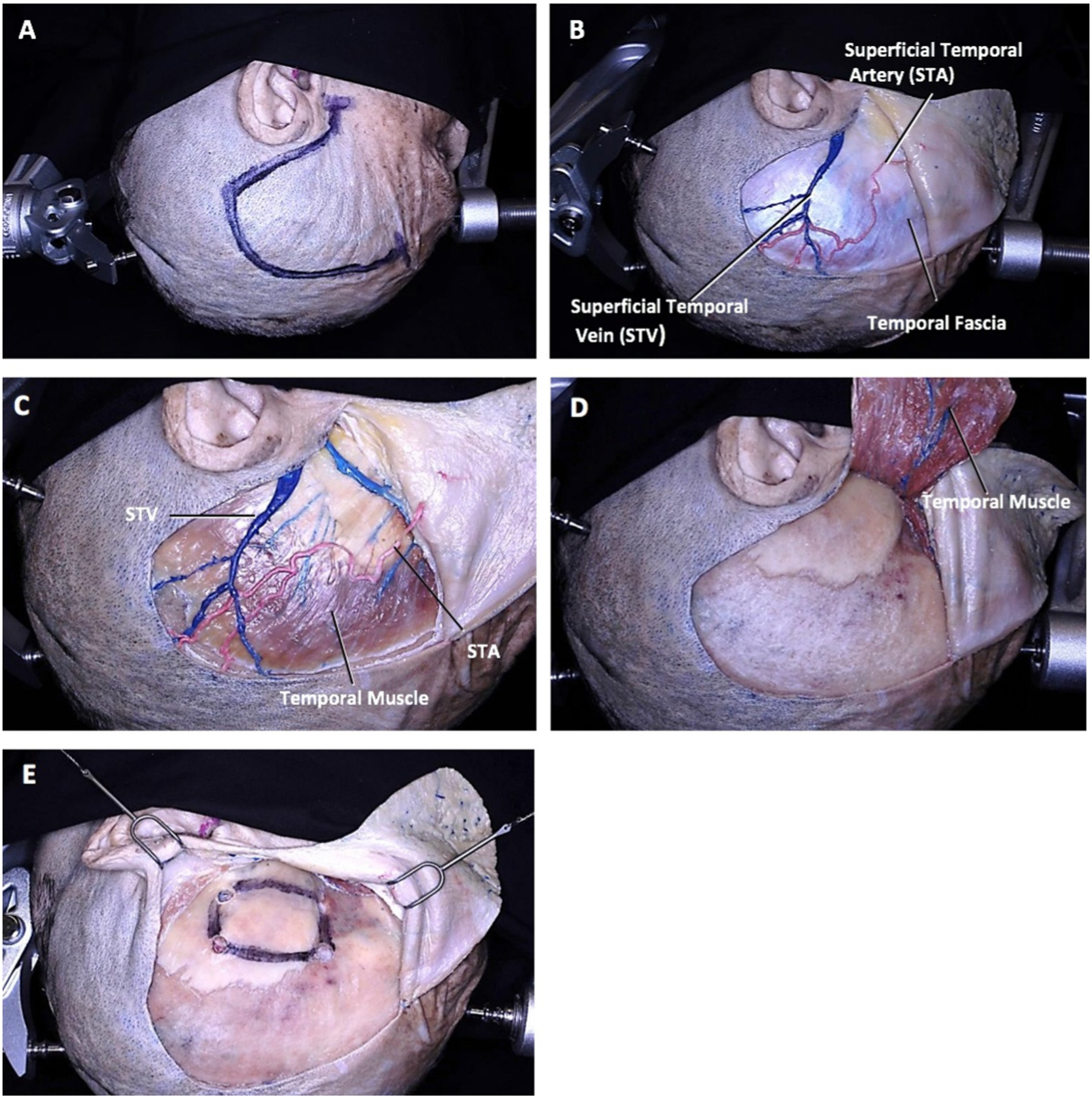

Fig. 1. Left temporal incision and craniotomy in stepwise manner. (A) After head fixation with the head holder, a question mark–shaped scalp incision is made, (B) Scalp flap is reflected toward the temporal fossa, (C) The superficial temporal artery (STA) and superficial temporal vein (STV) are preserved, (D) The temporal fascia and muscle are incised in the same manner as scalp incision and are reflected toward the temporal fossa, (E) The reflecting of the muscle is exposed the parietal and squamose part of the temporal bone. The size of the craniotomy is optional, the craniotomy was bordered in the squamose part of the temporal bone in this figure.

border of the hippocampus. *The amygdala* forms the anterior wall of the temporal horn of the lateral ventricle. The amygdala is separated from head of hippocampus via the uncal resses (Fig. 3A, D). Anterior segment of the uncus, which contains the amygdala, has a close anatomical relationship with the internal cerebral artery, (from the origin to bifurcation/trifurcation of middle cerebral artery) M1 segment of the middle cerebral artery and globus pallidus, therefore care must taken during the removal of the amygdala [14].

3.2. Surgical technique

The patient is placed supine position and the head is elevated 45° to decrease the venous pressure. The head is 90° rotated to the contralateral side, the sagittal plane is aligned parallel to the floor. A question mark-shaped scalp incision is made by extending from 1 cm anterior to the tragus to the lateral frontal area (Figs. 1A, B, 4A, B). The scalp flap is reflected anteriorly, care must taken the superficial temporal artery (STA), superficial temporal vein (Figs. 1C, D, 4C, D). The temporal fascia and temporal muscle are incised in a same manner as scalp incision. After reflecting the muscle toward the temporal fossa, the bur holes are placed below or/and above the squamous suture, optionally (Fig. 1E, 4E). Thereafter, a craniotomy around 3×4 cm is performed. After craniotomy, the dural incision is made in a horseshoe fashion and tacked toward the temporal fossa (After craniotomy, the dural incision is made in a ‘Y’ fashion) (Fig. 4F). The middle temporal gyrus is parallelly around 3 cm incised by starting 3 cm posterior to the

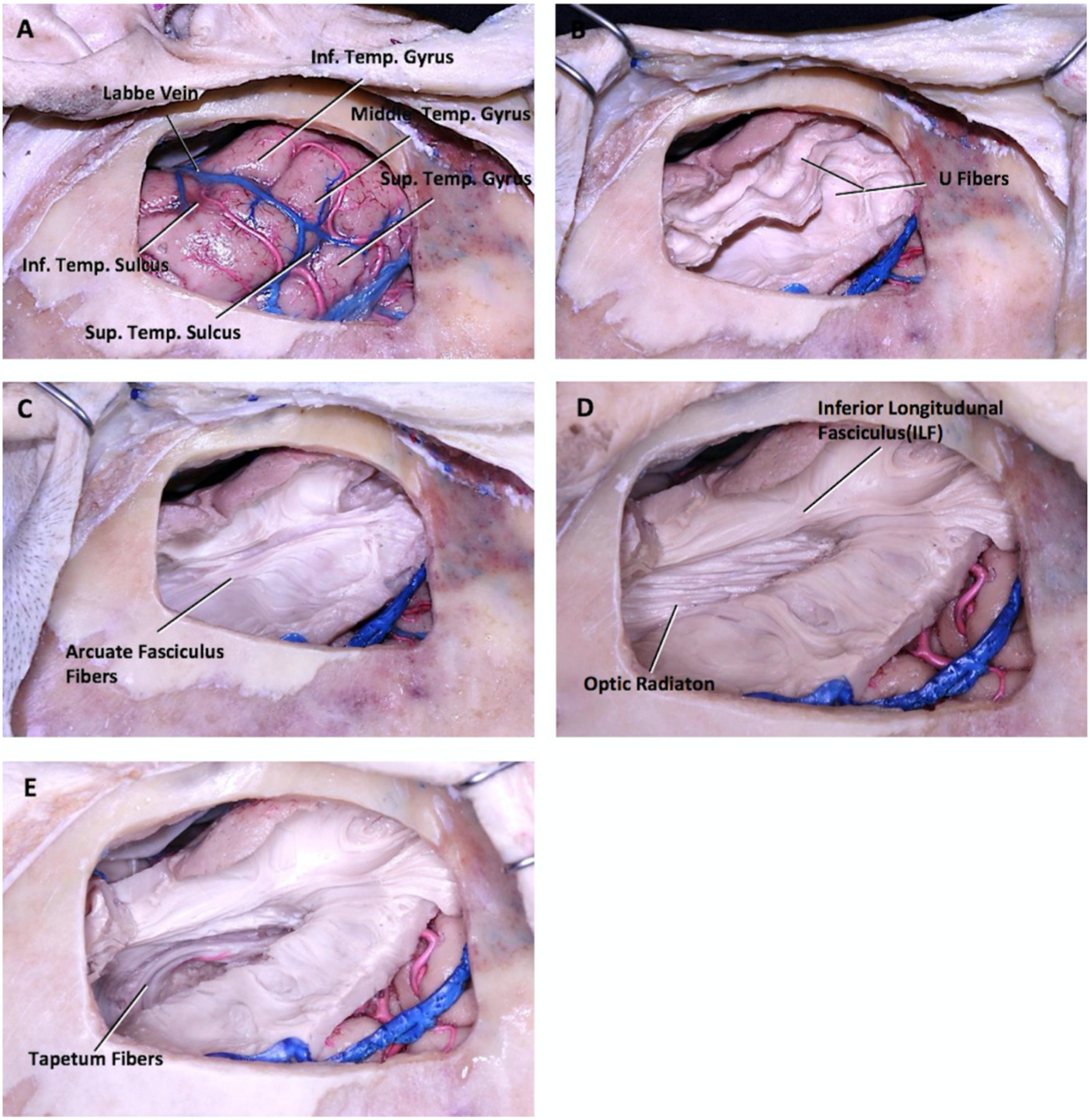

Fig. 2. The intracranial stages of the transcortical approach step by step. (A) After the temporal craniotomy and dural incision, the middle one third of the temporal gyri are exposed, (B) The decortication exposes the short association fibers (U fibers), (C) At a deeper point the Arcuate Fasciculus (AF) fibers are encountered, (D) The removal of the AF fibers exposes the IFOF, occipital extension of the anterior commissure fibers, and optic radiation fibers, (E) Before the ependyma of the temporal horn of the lateral ventricle, the white matter to be encountered lastly is the tapetal fibers. Ant = anterior, ILF = inferior longitudinal fasciculus, Inf. = inferior, Lat. = lateral, Post. = posterior, Sup. = superior, Temp. = temporal.

temporal pole (Fig. 5A, B). Until reaching the temporal horn of the lateral ventricle, it is accessed through the middle temporal gyrus in a anteroposterior fashion (Fig. 5C). If navigation system exists, the posterior limit of the corticectomy is marked the same axial level as the lateral mesencephalic sulcus. After entering into the ventricle, the structures such as, the hippocampus, fimbria, lateral, ventricular sulcus, collateral eminence, choroid plexus, inferior choroidal point, choroidal fissure, and amygdala, are exposed before starting the mesial temporal resection. The hippocampus is separated from the parahippocampal gyrus (subiculum) by incision of the arachnoid of the hippocampal sulcus. The parahippocampal gyrus is resected, extending from posterior part of the uncus to the level of the quadrigeminal plate by using the Cavitron Ultrasonic Surgical Aspirator (CUSA). During the resection, care must taken into the arachnoid membrane covering the neurocritical structures lying underneath as follows: the internal carotid artery, posterior communicating artery, P2 segment of the posterior cerebral artery, oculomotor nerve, and optic tract. The lateral geniculate body can be seen at the posterior limit of the hipocampal resection, and the optic tract represents as the upper limit of uncus resection. The medial border of the hippocampus is formed by choroidal fissure and inferior choroidal point. The choroid plexus is lifted to expose the fimbria of the fornix, which should be preserved to avoid postoperative memory defisit. The subpial

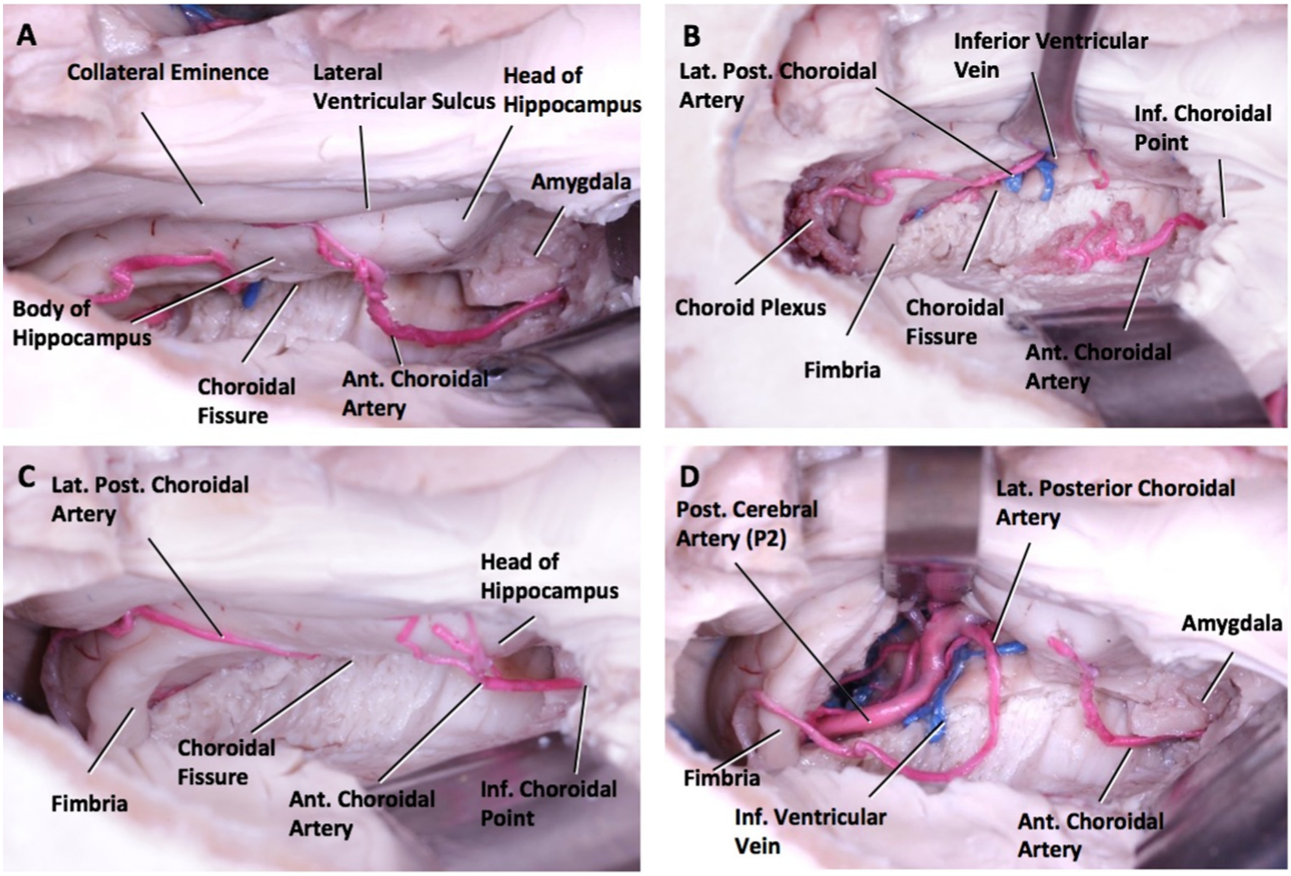

Fig. 3. Intraventricular-temporal horn stage. (A) After opening ependymal layer, the collateral eminence located lateral to hippocampus, the lateral ventricular sulcus separating the hippocampus and the collateral eminence, the hippocampus located between the collateral eminence laterally and choroidal fissure medially, the amygdala forming the anterior wall of temporal horn of the lateral ventricle, and anterior choroidal artery passing through the inferior choroidal point are exposed, (B) Proceeding backward and medialward, the fimbria of the fornix, the lateral posterior choroidal artery, and inferior ventricular vein are exposed, (C) The removal of the choroidal plexus exposes the fimbria of the fornix, (D) The opening the ambient cistern exposes the lateral posterior choroidal arteries are arise in from the posterior cerebral artery (PCA)–P2 segment in the ambient and quadrigeminal cistern. AF = Arcuate Fasciculus, Ant. = anterior, Inf. = inferior, Lat. = lateral, PCA = Posterior Cerebral Artery, Post. = posterior, Sup. = superior, Temp. = temporal.

dissection is performed along the lateral ventricular sulcus from the collateral eminence on lateral side and from the choroidal fissure on medial side by microdissector for *en bloc* resection of the *hippocampus* proper (Fig. 5D, E, F, Fig. 6A). After hemostasis, the dura is closed in a watertight fashion, the bone flap is replaced, the temporal muscle, fascia, galea and skin are closed properly.

4. Discussion

4.1. Anatomical considerations

For reaching the temporal horn of the lateral ventricle through the middle temporal gyrus, the AF ventral segment, IFOF, occipital extension of the anterior commissure, optic radiation and tapetal fibers are encountered, in order from the surface of the gyrus to the ventricle.

AF has two parts; dorsal and ventral segments [9]. The AF ventral segment extends from the middle and posterior parts of the superior gyrus and middle part of the middle temporal gyrus to the inferior frontal gyrus by passing through the lower part of the supramarginal gyrus and the frontoparietal operculum. The AF dorsal segment extends from the posterior part of the middle and inferior temporal gyri to the inferior and middle frontal gyri by passing through the angular gyrus and frontoparietal operculum. The AF ventral segment is related to phonological language processing, and the AF dorsal segment is related lexical and semantic language processing [13]. Damage to the AF may result in speech disorders.

The IFOF connects the inferior frontal lobe and dorsolateral prefrontal cortex to the temporal lobe and the occipital lobe. The IFOF has an important role in high neurocognitive functions such as, picture naming, object recognition, naming of sounds and recognition of speech [15,16]. Therefore, damage to the IFOF can cause neurocognitive defect and sensorial disphasia (difficulty in meaning of words). The uncinate fasciculus (UF) is located at the limen unsula, and a connection between the anterior temporal lobe and orbitofrontal cortex. Although, role of UF is not well known, it is considered as it has a role in recognizing faces, actions, and objects and also emotion [17,18].

The inferior longitudinal fasciculus (ILF) is located within the inferior temporal gyrus and located below at the level of the temporal horn of the lateral ventricle. It connects the temporal pole to the dorsolateral occipital cortex. The ILF is related to object identification, recognition and has been claimed to as an indirect semantic language pathway [9]. However damage to the ILF in dominant hemisphere is very unlikely to cause morbidity [19].

Damage to the most anterior part of optic radiation fibers, named Meyer's loop, may in an upper contralateral quadrantanopia. The Meyer's loop is located around 3 cm posterior to the temporal pole and at the same level as the tip of the temporal horn of the lateral ventricle [20,21].

Fig. 4. The intraoperative pictures – 1. (A) Lateral view and (B) superior view, the head position and scalp incision, (C) The question mark-shaped incision after sterilization of the surgical field, (D) Reflecting the scalp flap and temporal muscle toward the temporal fossa, (E) The placement of bur holes, (F) The dural opening over and parallel to the middle temporal gyrus in a 'Y' fashion.

The anterior choroidal artery arises from posterior wall of the internal carotid artery and courses posteriorly, passes through the choroidal fissure to enter into the temporal horn at the inferior choroidal point. This artery gives off the uncal and hippocampal arteries to supply the anterosuperior segment of uncus and hippocampus [22]. The lateral posterior choroidal arteries arise from the P2 segment of the posterior cerebral artery in the ambient and quadrigeminal cisterns, and passes through the choroidal fissure at the level of the fimbria, crus, and body of the fornix to reach the choroid plexus in the temporal horn of the lateral ventricle. There are frequent anastomoses between the branches of the anterior and lateral posterior choroidal arteries on the surface of the choroid plexus [23]. The inferior ventricular vein drains into the roof and wall of the temporal horn of the lateral ventricle via subependymal veins, passing into the choroidal fissure to join the peduncular segment of basal vein at the junction of the crural and ambient cisterns [24].

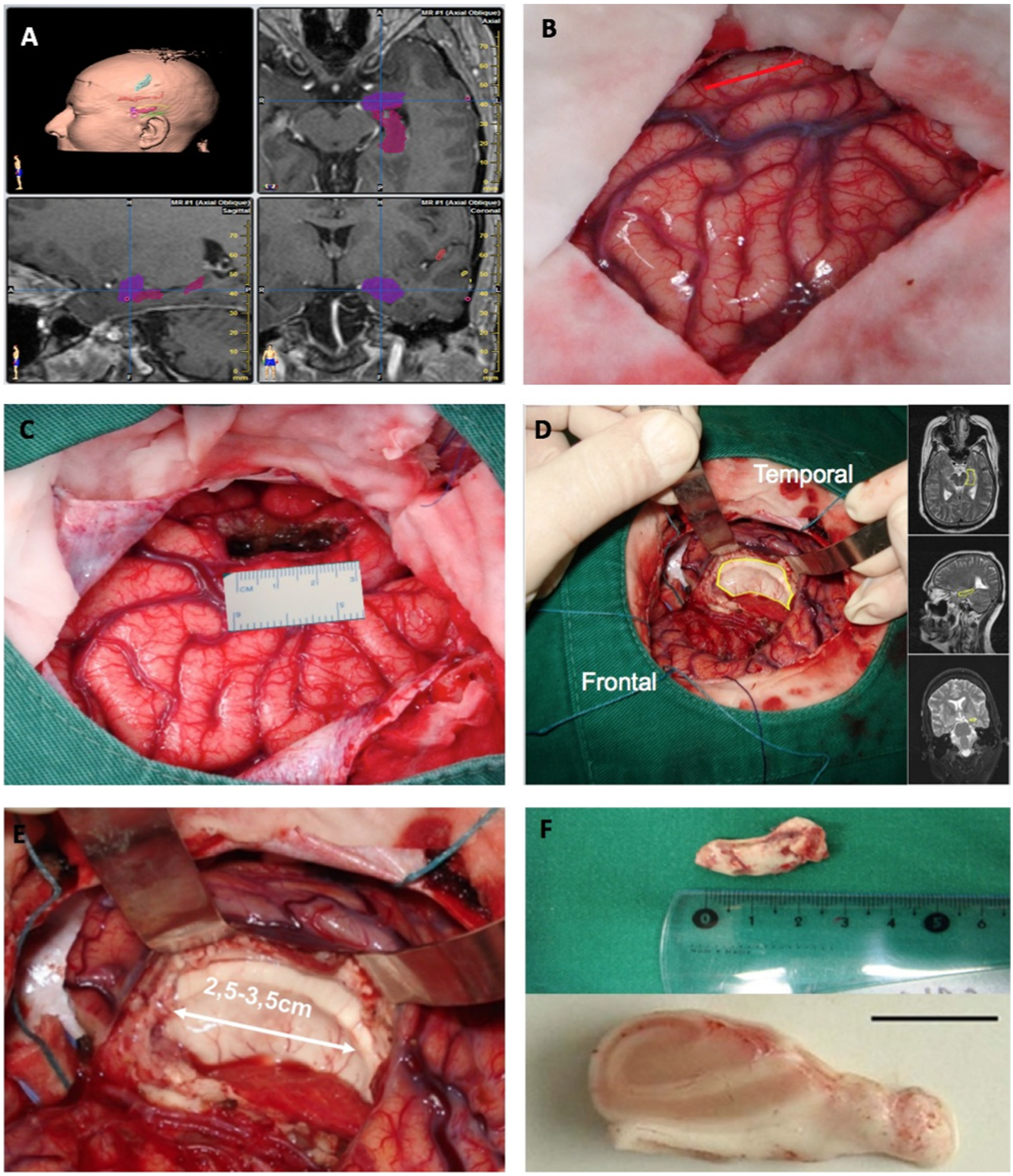

Fig. 5. Intraoperative pictures – 2. (A) The navigation device demonstrating the shortest route to the amygala and hippocampus through the middle temporal gyrus, (B, C) The linear cortical incision around 3 cm to the middle temporal gyrus, (D, E) Performing the subpial dissection for hippocampectomy. (F) Hippocampus proper is removed *en bloc* from the hippocampal tail.

The most important step for the good surgical outcomes is the selection of the most appropriate patient by evaluating the preoperative invasive or non-invasive investigations. The SelAH is used for patients with a neuropsychological profile consistent with mesial temporal lobe epilepsy, a temporal lobe electroencephalographic abnormality, and a mesial temporal lobe lesion revealed on MRI (hippocampal sclerosis), which is the most ideal indicated factor [25]. After a decision making of performing the surgical treatment, the next step is to decide which surgical technique will be performed. Each surgical technique has own advantages and disadvantages. Although numerious alternatives have been developed to the anterior temporal lobectomy (ATL), there does not

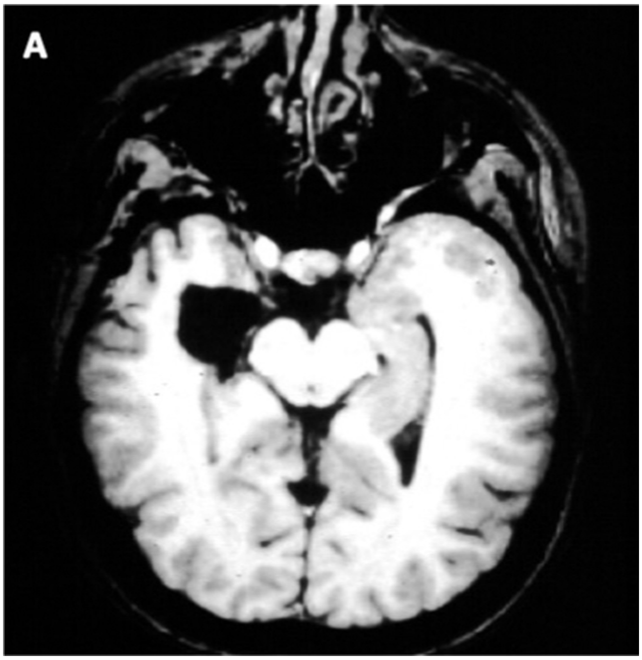

Fig. 6. Post-op fluid-attenuated inversion recovery MRI. (A) MRI shows the *en bloc* removal of the amygdala and hippocampus.

appear a significant difference in seizure outcome between SelAH and ATL [25,26]. However, it has been noted that the SelAH provides a better neuropsychological outcomes than the ATL in selected patients [27,28]. The goal of epilepsy surgery is to achieve seizure-free on patients while protecting neurological functions and/or to apply this procedure with having more less neurological damage. Clinical studies conducted considering long term outcomes, there have been a correlation between size of the resected mesial temporal tissue and surgical success [29,30]. The complete removal of the hippocampus without the residual tissue are critical to achieve postoperative long term free-seizure [1,31].

There have been numerious studies that compare long term seizure outcomes between SelAH and ATL. Most of clinical studies has not found a significant difference between outcomes of two approaches [32–34]. Mansouri et al. compared the seizure and neurocognitive outcomes of both approaches, although they have not found a significant difference between long term seizure outcomes each other, they reported that ATL group more likely to have early seizure but seizure-free patients in ATL group have more resistance to have a seizure than the patients in SelAH group [35]. In addition to some studies, although the seizure outcomes of ATL group is better than SelAH group [36,37], there has not been any study that have noted that the seizure outcomes of SelAH group were significantly better than the outcomes in ATL group. However, there is, two different meta-analysis studies even reported that seizure recurrence rate in patients in ATL group is less than the patients in SelAH group [38,39].

Damage to the inferior longitudinal fasciculus (ILF) may cause negative neurocognitive. The ILF connects anterior parts of the temporal lobe to the fusiform gyrus and the occipital lobe and it has been claimed that this connection has a role in learning and remembering of visual stimuli. Therefore, especially neocortical resection of this area can cause problems in memory function [40]. Tanriverdi et al. evaluated Intelligence quotient (IQ) and memory outcomes in 256 patients who had epilepsy surgery at 1-year follow-up and resulted that those parameters are higher level in SelAH group than in ATL group. While verbal memory disfunction was observed in patients with left-sided resection in SelAH group, nonverbal memory disfunction was observed especially in patients with right-sided corticoamygdalohippocampectomy [26]. Another study was reported that especially verbal memory defect has been observed in patients with dominant hemisphere resection in ATL group [41]. Independent of the surgical method, It has been founded that verbal memory defect has much higher rate in patients with left-sided epilepsy surgery. On the other hand, it was noted that visual encoding, verbal and visual short-term memory and visual working memory outcomes in patients in SelAH group is better compared to temporal lobectomy patients [34]. Notable that naming defect has been observed frequently in ATL group patients with dominant hemisphere resection [42]. Another study displayed that patients in SelAH group is better than patients in ATL group to prevent naming, respectively [35]. Overall, numerious studies were noted that neurophysiological outcomes of patients in SelAH group is better compared to patients in ATL group [43–45].

In clinical studies noted that the visual field defect in patient in ATL group is more often than patients in SelAH group [20,46–48]. in trans-sylvian SelAH method, it was also reported that the risk of damaging optic radiations is less likely compared to patients in ATL group [49]. The transsylvian SelAH method first defined by Yasargil allows resection of mesial temporal structures through the slyvian fissure without touching temporal neocortex [7]. In this procedure, the slyvian fissure is opened to expose the anterior insular cortex, limen insulae, mesial uncus and temporal pole. Thereafter, the inferior limiting sulcus is opened at the level of the limen insula. The risk of vascular injury or vasospasm in this approach is much more higher compared to transcortical approach due to blood breakdown to basal cistern and dissections of slyvian vessels [50]. The most anterior border of the Meyer's loop passes 10.6 ± 3.4 mm behind the anterior insular point, the junction of the limen insula and inferior limiting sulcus. Although the transamygdalar approach spare the Meyer's loop, the exposure of the posterior part of the hippocampus is needed the extension of the incision backward, which dangers the optic radiation fibers. The posterior SelAH approaches (supracerebellar infratentorial and posterior interhemispheric) have limited exposure to the amygdala and uncus. [3,4,51].

5. Conclusion

The main goal of the surgical treatment of mesial temporal lobe epilepsy is to relief the patient seizure-free while preserving neurophysiological and normal functions. Although the SelAH procedure has a better neuropsychological outcomes than the ATL, among the SelAH procedures, there has been a clear evidence that shows the one approach is superior to another one about reducing the clinical complications and rate of seizure recurrence. However, the middle temporal gyrus approach provides the better exposure to the mesial temporal lobe structures than anterior (transylvania) approach, which has a limited access to the posterior part of the mesial temporal lobe, and posterior approach, which has a limited access to the anterior part of the mesial temporal lobe, to resect the tissue that is directly correlated with achievement postoperative long term free-seizure.

A better anatomical and functional understanding the neurocritical structures of the temporal lobe is crucial for safer and more accurate surgery.

Conflicts of Interest/Disclosures

The authors declare that they have no financial or other conflicts of interest in relation to this research and its publication.

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