**Turk Neurosurg** 31(3):422-431, 2021

*Original Investigation*

**DOI:** 10.5137/1019-5149.JTN.31629-20.2

Received: 15.07.2020
Accepted: 26.10.2020

Published Online: 29.03.2021

# Surgical Treatment of Temporal Lobe Epilepsy and Micro-Neuroanatomical Details of the Medial Temporal Region

Atilla ERDEM[1], Ayse KARATAS DEMIRCILER[2], Serdar SOLMAZ[1], Onur OZGURAL[1], Umit EROGLU[1], Alain WAMBE[1], Ozan TEKNECI[1]

[1]Ankara University School of Medicine, Department of Neurosurgery, Ankara, Turkey
[2]Izmir Kâtip Celebi University School of Medicine, Department of Neurosurgery, Izmir, Turkey

**Corresponding author:** Atilla ERDEM ✉ atillaerdem@ankara.edu.tr

## ABSTRACT

**AIM:** To evaluate the long-term efficacy of temporal lobe epilepsy (TLE) surgery, and to emphasize the factors affecting seizure outcomes such as surgical technique nuances and micro-neuroanatomical details in TLE cases.

**MATERIAL and METHODS:** In this retrospective analysis, 238 patients who underwent epilepsy surgery at Ankara University (Faculty of Medicine, Department of Neurosurgery) between 1990 and 2019 were included. All patients presented with symptoms of TLE. They were divided into two groups: those with neoplastic lesions and those with non-neoplastic brain lesions presenting with medically intractable epilepsy. In the non-neoplastic group, the patients underwent anterior temporal lobectomy with amygdalo-hippocampectomy (ATL+AH), whereas in the neoplastic group, the patients underwent tumor resection in addition to ATL+AH.

**RESULTS:** This study included 126 female (52.9%) and 112 male (47.1%) patients. The mean duration of epilepsy was 14.65 ± 9.29 years (0.08–46 years). The number of patients in the non-neoplastic and neoplastic groups was 190 and 48, respectively. The mean duration of follow-up was 15.82 ± 6.55 years (1–28 years). In the neoplastic and non-neoplastic groups, the Engel I seizure-free rates were 91.6% (44/48) and 90.5% (172/190), respectively. Furthermore, no mortality was observed among the groups.

**CONCLUSION:** Overall, effective seizure control was achieved with acceptable morbidity and complication rates in the neoplastic and non-neoplastic groups with surgical and micro-neuroanatomical nuances.

**KEYWORDS:** Amygdalo-hippocampectomy, Anterior temporal lobectomy, Epilepsy surgery, Microneuroanatomy, Refractory temporal lobe epilepsy

**ABBREVIATIONS: TLE:** Temporal lobe epilepsy, **MRI:** Magnetic resonance imaging, **ATL+AH:** Anterior temporal lobectomy with amygdalo-hippocampectomy, **EEG:** Electroencephalography, **PET:** Positron emission tomography, **SPECT:** Single-photon emission computed tomography, **ILAE:** International League Against Epilepsy, **MCA:** Middle cerebral artery, **AChA:** Anterior choroidal artery, **PCA:** Posterior cerebral artery, **GTCS:** Generalized tonic-clonic seizures, **CPS:** Complex partial seizure, **SAH:** Selective amygdalo-hippocampectomy, **ECoG:** Electrocorticography

Atilla ERDEM : 0000-0001-9942-3174
Ayse KARATAS DEMIRCILER : 0000-0003-4143-9549
Serdar SOLMAZ : 0000-0001-7889-3396
Onur OZGURAL : 0000-0001-5797-4373
Umit EROGLU : 0000-0001-8623-071X
Alain WAMBE : 0000-0003-2044-1690
Ozan TEKNECI : 0000-0002-5037-3361

## INTRODUCTION

Epilepsy is a disorder leading to behavioral, psychological, and social problems and the impairment of quality of life. Nearly 40% of patients with epilepsy have medically intractable epilepsy despite the recent use of new antiepileptic drugs (3). Surgical treatment is an important therapeutic approach for seizure control in patients that are considered good candidates based on comprehensive investigations. In adult patients, temporal lobe epilepsy (TLE) is the most common form of epilepsy. Most surgically treated patients with medically intractable seizures have TLE. Previous studies have reported the outcomes of surgical treatments for TLE (8,20,41,42,50,59). In patients with TLE, the most common pathological disorder is mesial temporal sclerosis (5). Unilateral structural lesions such as hippocampal sclerosis on cranial MRI are associated with good prognosis after surgery (20,23).

Among the different surgical techniques used in epilepsy surgery centers, anterior temporal lobectomy with amygdalo-hippocampectomy (ATL+AH) is the most common and successful surgical procedure for TLE (7,20,59). Aside from the selective amygdalo-hippocampectomy method (which includes the excision of the lateral part of the amygdaloid nuclear complex, hippocampal body, and parahippocampus extending from the hippocampal fimbriae to the collateral sulcus) developed by Niemeyer and then Wieser and Yasargil (32,61,62), other surgical techniques which use neuronavigation and stereotactic approaches have also been reported in recent years (37). Indeed, seizures may recur after undergoing surgeries for TLE and in some cases, reoperation may be required. Moreover, several studies have reported the outcomes of reoperation for recurrent TLE and concluded that a more complete resection of the mesiobasal structures can prevent seizure recurrence and the need for reoperation (10,12). Because of the complexity of mesial temporal region, surgeries performed in this area require detailed micro-neuroanatomical knowledge and a good micro-neurosurgical technique. The surgical technique used during surgeries is based on the anatomical study entitled "Microsurgical anatomy of the hippocampal arteries" (11).

In this study, we analyzed the clinical features, preoperative investigations, postoperative pathological results, and seizure outcomes of 238 patients with medically intractable TLE and discussed the effect of surgical techniques and micro-neuroanatomical details on the patient outcomes. Moreover, the surgical technique for ATL+AH was used. This study also reflects the results of the clinical series and 29 years of experience in the field of TLE surgery (9-11,13,15,21,22).

## MATERIAL and METHODS

### Patients

In this study, a total of 238 patients with medically intractable TLE who underwent surgical treatment at Ankara University (Faculty of Medicine, Department of Neurosurgery) between 1990 and 2019 were assessed. Ankara University Faculty of Medicine Human Research Ethics Committee approval was obtained for this study (Decision No: I2-121-20). The patients' data were examined retrospectively. In our series, three patients with focal cortical dysplasia and hippocampal sclerosis association were excluded from the study. The classification of epileptic seizures was determined in accordance with the International League Against Epilepsy (ILAE) criteria (43).

### Preoperative Assessment

First, a detailed history of the patients was recorded. The frequency, duration, severity, and clinical features of the epileptic seizures were questioned chronologically. Moreover, the patients were questioned about seizure-precipitating factors, their response to various medications, and the amount of dosages administered. Afterwards, physical and neurological examinations were performed. Visual field examinations were performed using the Goldmann visual field test. Routine awake EEG, cranial MRI, neuropsychological tests, and psychiatric examination were performed. In selected patients, interictal PET and SPECT were performed. Long-term video-EEG monitoring was used when appropriate. Video-EEG monitoring was repeated using sphenoidal and subdural strip electrodes when deemed necessary.

All patients underwent neuropsychological assessment. Firstly, the mood and mental status of the patients were evaluated with regard to their eligibility to undergo neuropsychological tests. Memory functions were assessed using a test battery that included verbal and nonverbal memory tests. Moreover, if signs of dysfunctional memory were observed, the patients were evaluated with regard to their eligibility to undergo surgery.

Video-EEG monitoring was performed at Gazi University, Department of Neurology, Ankara. Electrodes were placed in accordance with the International 10-20 system. Prior to patient monitoring, the dosages of the antiepileptic medications were reduced or stopped to precipitate seizures. The seizure onset focus or area was frequently investigated by evaluating the interictal recordings and ictal changes during sleep and wakefulness in different EEG montages. The patients were monitored continuously until at least three or more typical seizures were recorded. If the seizure onset could not be clearly localized, bilateral sphenoidal and temporal subdural strip electrodes were placed to identify the ictal onset of seizures.

After these evaluations were performed, the patients were referred for a multidisciplinary team approach. Surgical treatment option was adopted if data suggested a single focus. A decision was then made regarding the most appropriate surgical technique for the patient.

### Surgical Technique

The procedures of the anterior temporal lobectomy combined with amygdalo-hippocampectomy (ATL+AH) are summarized below:

Firstly, the lateral part of the superior temporal gyrus in conjunction with the temporal pole is excised and separated as a pathology sample. Then, the residual medial part of the superior temporal gyrus is excised subpially along the opercular surface of the temporal lobe to reach the infero-lateral part of the circular sulcus of the insula. In this stage, the branches of the middle cerebral artery (MCA) are exposed under their pia mater and the pia mater is left intact. In the next stage, the circular sulcus of the insula is cut lateral to the infero-lateral M2 segment of the MCA and the circular sulcus vein, and the temporal horn of the lateral ventricle is accessed. The resection is extended anteriorly in order to remove the uncus subpially medial to the free edge of the tentorium and posteriorly in order to gain access to the collateral trigone. Exposing the collateral trigone allows the removal of the tail segment of the hippocampus. In this phase, the third cranial nerve is exposed under its pia-arachnoid sheath just medial to the free edge of the tentorium and the pia mater is left intact. The lateral part of the amygdaloid nuclear complex is then removed. After that, the choroid plexus is found and reflected superiorly (in other words, to the thalamus), and the tenia fimbriae is exposed. The purpose of this manipulation is to expose the inferior choroidal point (which is the inferior termination of the choroidal fissure). The anterior choroidal artery (AChA) reaches the ventricle at that point (Figure 1).

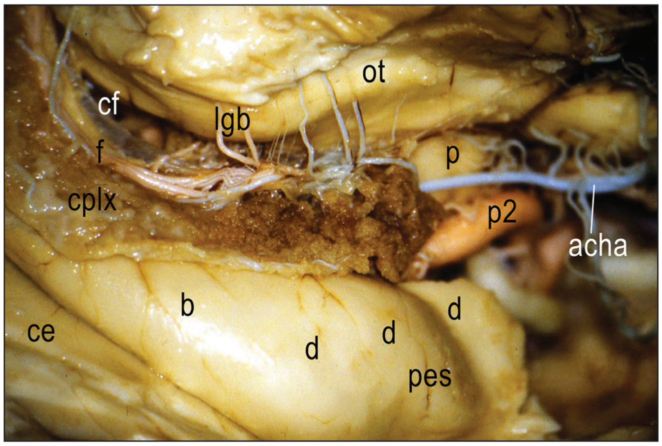


**Figure 1:** Right hippocampal area: In this cadaveric specimen, internal carotid artery was filled with blue-colored latex and basilar artery was filled with red-colored latex in order to identify the course of the AChA and P2 segment of PCA. Vital neural and vascular structures related to this operation are shown in this figure. The hippocampal digitations **(d)**; pes hippocampi **(pes)**; body of hippocampal formation **(b)**; collateral eminence **(ce)**; choroid plexus **(cplx)**; P2 segment of PCA **(p2)**; fimbria **(f);** choroidal fissure ***(cf)***; cerebral peduncle **(p)**; optic tract **(ot)**; and lateral geniculate body **(lgb)**.

Another purpose of this manipulation is to use the tenia fimbriae as a route to enter the ambient cistern. The tenia fimbriae route does not include dense vascular structures compared to the tenia choroidea route. The practice of this technique is shown in Figures 2A, B and 3A, B, respectively. As a result, it enables the protection of AChA, the posterior cerebral artery (PCA), and the optic tract and cerebral peduncle under their piamater sheaths during the surgery. In the subsequent phase, the hippocampal arteries and drainage veins are detected and coagulated by entering the uncal sulcus anteriorly and the hippocampal sulcus posteriorly. The purpose of the exposure of these sulci is to provide a safe coagulation while staying away from the parent vascular structures such as the PCA and the basal vein of Rosenthal. After that, the head and the whole body of the hippocampus are removed extensively including a part of the hippocampal tail and the subiculum remnant. Furthermore, the final stage of the operation is shown in Figure 4.

The important steps of the operation are summarized as follows:

1. Anterior temporal polectomy while leaving residual tissue of the superior temporal gyrus medially.
2. Subpial removal of the superior temporal gyrus remnant and using this removal as a guide to reach the infero-lateral part of the circular sulcus of the insula.
3. Incision of the circular sulcus just lateral to the M2 segment of the MCA and the circular sulcus vein. This incision is extended anteriorly to complete the cutting of the temporal stem and to enter the temporal horn of the lateral ventricle. Moreover, the uncus is removed subpially and posteriorly to gain access to the collateral trigone in order to remove the hippocampal tail.
4. Reflecting the choroid plexus upward and opening the tenia fimbriae in order to enter the ambient cistern.
5. Opening the uncal sulcus anteriorly and the hippocampal sulcus posteriorly and coagulating the hippocampal feeding arteries and drainage veins within these sulci while staying away from the parent vessels.
6. Removal of the hippocampal head, body, and anterior part of the hippocampal tail and the subiculum remnant.

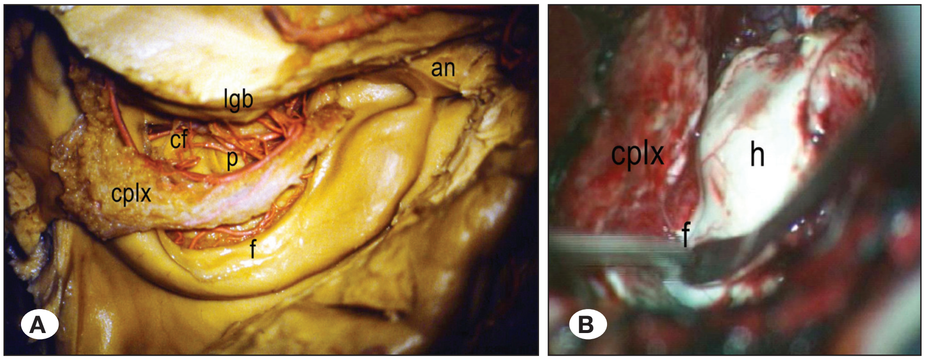


**Figure 2:** In this figure, the attachment of the choroid plexus to the tenia choroidea superiorly and to the tenia fimbria inferiorly is shown in the cadaveric specimen **(A)** and at the operation **(B)**. Choroid plexus **(cplx)**; choroidal fissure **(cf)**; cerebral peduncle **(p)**; amygdaloid nuclear complex **(an)**; fimbria **(f)**; lateral geniculate body **(lgb)**; hippocampus **(h)**.

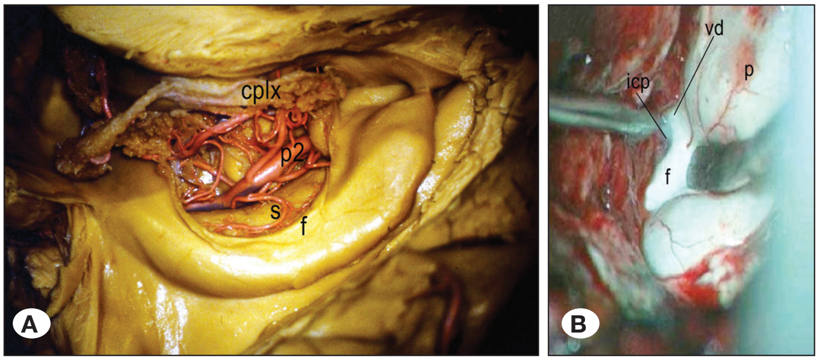


**Figure 3:** The reflection of the choroid plexus (cplx) superiorly in order to expose the tenia fimbria route which consists of fewer vascular structures compared to the tenia choroidea route. This maneuver is shown in the cadaveric specimen **(A)** and at the operation **(B)**. In Figure 3B, the exposition of the vertical digitation **(vd)** and inferior choroidal point **(icp)** is also shown. Anterior choroidal artery reaches the ventricle at this point and not visible because it was protected under its pia-arachnoideal layer. Pes hippocampi **(p)**; fimbria **(f)**; P2 segment of PCA **(p2)**; subiculum **(s)**.

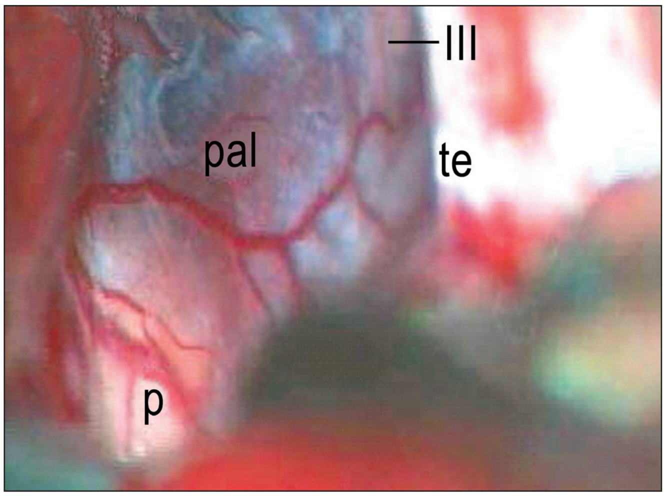


**Figure 4:** Final stage of the operation. Right-sided amygdalo-hippocampectomy procedure has been completed. After the resection, the right third nerve **(III)** and cerebral peduncle **(p)** are shown which are protected under their pia-arachnoideal layers **(pal)**. The free edge of the tentorium **(te)** is also shown. Only the exposed vital structures can be preserved during surgery, but having them exposed does not necessarily mean that their pia-arachnoideal layer should be peeled away.

In conclusion, our familiarity with the micro-anatomical details of this area enabled us to remove the epileptogenic tissues including the hippocampal head, body, tail, and subiculum remnants extensively.

### Postoperative Follow-Up

The patients were discharged with appropriate medical treatment. All patients attended regular follow-up every 3 months. Cranial MRI was performed routinely during the postoperative follow-up period. Postoperative results were classified using Engel's criteria (8,20). Postoperatively, all samples were evaluated by pathologists. In the seizure-free group, the dosage of medical treatment was reduced and stopped within 2 years. Neuropsychological tests were performed to all patients 1 year after the operation.

### Statistical Analyses

All data were analyzed using the SPSS 11.5 software (SPSS Inc., Chicago, Illinois, USA). The mean ± standard deviation and median (minimum-maximum) for quantitative variables and the number of patients (percentage) for qualitative variables were used as descriptors. The difference between the qualitative variables with two categories in terms of quantitative variables was determined using the Mann-Whitney U test. The relationship between two qualitative variables was examined using Fisher's exact test. Furthermore, the statistical significance level was set at 0.05.

## RESULTS

In this study, a total of 238 patients were examined. One hundred twenty-six patients were female (52.9%) and 112 male (47.1%). The patients' average age was 27.46 years (3–70 years). The average duration of seizure was 14.65 years (0.08–46 years). Fifty-four patients (47%) had febrile convulsion, 10 patients (24.5%) had head trauma, 10 patients (4%) had central nervous system infections, and 3 patients (1.2%) had a history of difficult birth. The seizures were classified as complex partial seizures (CPS) (n=127, 53.3%), secondarily generalized tonic-clonic seizures (GTCS) (n=30, 13%), and CPS plus secondarily GTCS (n=81, 35.1%) (Table I). Neurological examinations revealed no major neurological deficits in the patients.

Preoperative clinical and electrophysiological studies showed left temporal focus in 130 patients (54.6%) and right temporal focus in 108 patients (46.4%). Based on the brain MRI results, 28 (11.7%) patients were normal, 62 (26.1%) presented with neoplastic lesions, and 148 (62.2%) presented with non-neoplastic lesions (Table II). In 16 patients with bilateral EEG abnormality, invasive monitorization was performed in order to localize the ictal onset. One hundred thirty patients (54.6%) underwent left-sided ATL+AH operation, whereas 108 patients (46.4%) underwent right-sided ATL+AH operation. Furthermore, tumor resection was combined with ATL+AH in the neoplastic group (20.2%) (Table I, III).

The histopathological results of the operation materials were classified in two groups: the neoplastic group (n=48) and non-neoplastic group (n=190) (hippocampal sclerosis or gliosis (n=176), cystic lesions (n=2), dysplasias (n=4), and vascular lesions (n=8) (Table III). In the postoperative period, the histopathological examination of the patients with febrile convulsion showed that a high incidence of hippocampal sclerosis was considered statistically significant (p=0.041).

**Table I:** Characteristics of Patients

| Variables | Value |
|---|---|
| **Age** | |
| Mean ± SD | 27.46 ± 10.17 |
| Median (Min.-Max.) | 26.00 (3.00-70.00) |
| **Gender** | **n (%)** |
| Male | 112 (47.1) |
| Female | 126 (52.9) |
| **Febrile Convulsion** | **n (%)** |
| Absent | 61 (53.0) |
| Present | 54 (47.0) |
| **Trauma** | **n (%)** |
| Absent | 38 (79.2) |
| Present | 10 (20.8) |
| **Type of Seizure** | **n (%)** |
| CPS | 127 (53.3) |
| GTCS | 30 (12.6) |
| CPS+GTCS | 81 (34) |
| **Epilepsy Duration** | |
| Mean±SD | 14.65 ± 9.29 |
| Median (Min.-Max.) | 14.00 (008-46.00) |
| **Side of Surgery** | **n (%)** |
| Right | 108 (45.4) |
| Left | 130 (54.6) |
| **Histopathology** | **n (%)** |
| 1* | 190 (79.8) |
| 2† | 48 (20.2) |
| **Follow-up** | **n (%)** |
| ≤ 5 years | 26 (10.9) |
| 6-10 years | 17 (7.2) |
| 11-15 years | 65 (27.3) |
| > 15 years | 130 (54.6) |
| **Engel's Classification** | **n (%)** |
| 1 | 216 (90.7) |
| 2 | 7 (3.0) |
| 3 | 9 (3.8) |
| 4 | 6 (2.5) |

***CPS:** Complex partial seizure, **GTCS:** Generalized tonic-clonic seizures*
**Non-neoplastic etiology, †Neoplastic etiology.*

**Table II:** Patients' MRI Findings

| MRI findings number | n (%) |
|---|---|
| Normal | 28 (11.7) |
| Neoplastic lesion | 62 (26.1) |
| Non-neoplastic lesion | 148 (62.2) |

**Table III:** The Etiologies and Postoperative Complications

| Etiology | n (%) |
|---|---|
| Tumoral lesions | 48 (20.2) |
| Non-tumoral lesions | |
| Vascular lesions | 8 (3.4) |
| Other | 182 (76.4) |
| **Complications/Morbidity** | **n (%)** |
| Hydrocephalus | 2 (0.8) |
| Transient dysphasia | 7 (2.9) |
| Subdural hematoma | 2 (0.8) |
| Visual field defect (Contralateral superior quadrantanopia) | 2 (0.8) |
| Hemiparesis | 1 (0.4) |
| Surgical cavity hematoma | 1 (0.4) |
| Transient amnesia | 3 (1.3) |
| Dysnomnia | 7 (2.9) |
| Memory deficit | 11 (4.6) |

Overall, the seizure-free (Engel Grade I) rate at the postoperative follow-up period was 90.7% (n=216) in 238 patients. Three percent (n=7) of the patients were classified with Engel Grade II, 3.8% (n=9) Engel Grade III, and 2.5% (n=6) Engel Grade IV (Table I). In the neoplastic and non-neoplastic groups, the Engel I seizure-free rates were 91.6% (44/48) and 90.5% (172/190), respectively (Table IV).

The patients were grouped based on their postoperative follow-up duration (1–5 years, 6–10 years, 11–15 years, and >15 years) (Table I). In these groups, the number of patients were 26 (10.9%), 17 (7.2%), 65 (27.3%), and 130 (54.6%), respectively. Furthermore, no statistically significant association was observed between postoperative seizure outcome and age (p=0.142) and between postoperative seizure outcome and gender (p=0.136) (Table IV).

Postoperatively, 25 patients had various complications, such as hydrocephalus (n=2), transient dysphasia (n=7), subdural hematoma (n=2), visual field defect (n=2), hemiparesis (n=1), surgical cavity hematoma (n=1), transient amnesia (n=3), dysnomia (n=7), and newly developed memory deficit (n=11) (Table III). In this group, no mortality or permanent morbidity was observed.

**Table IV:** Distribution of Variables According to Seizure Type

| Variables | | Engel's Classification | | | | p |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| **Gender, n (%)** | Male | 99 (45.6) | 2 (28.6) | 6 (66.7) | 5 (83.3) | 0.136[a] |
| | Female | 117 (54.4) | 5 (71.4) | 3 (33.3) | 1 (16.7) | |
| **Histopathology, n (%)** | 1* | 172 (79.6) | 5 (71.4) | 7 (77.7) | 6 (100.0) | 0.157[a] |
| | 2† | 44 (21.4) | 2 (28.6) | 2 (22.3) | 0 (0.0) | |
| **Febrile Convulsion, n (%)** | Absent | 55 (51.4) | 1 (100.0) | 4 (100.0) | 0 (0.0) | **0.041[a]** |
| | Present | 52 (48.6) | 0 (0.0) | 0 (0.0) | 2 (100.0) | |
| **Trauma, n (%)** | Absent | 34 (82.9) | 1 (100.0) | 2 (66.7) | 1 (33.3) | 0.147[a] |
| | Present | 7 (17.1) | 0 (0.0) | 1 (33.3) | 2 (66.7) | |
| **Age** | Mean ± SD | 27.34 ± 10.14 | 33.86 ± 11.05 | 28.25 ± 11.00 | 21.33 ± 5.82 | 0.142[b] |
| | Median (Min.-Max.) | 26.00 (3.00-70.00) | 35.00 (22.00-55.00) | 29.00 (11.00-43.00) | 22.50 (14.00-29.00) | |

***a:** Fisher-exact test, **b:** Mann-Whitney U test, *Non-neoplastic etiology, †Neoplastic etiology.*

**Table V:** Outcomes and Data of Different Studies

| Author | Number of patients | Surgery type | Follow-up period (years) | Seizure outcome | Percentage of seizure free |
|---|---|---|---|---|---|
| Wieser et al., 2001 (60) | 369 | SAH | 7 | Engel 1 | 62% at 5-year follow-up |
| McIntosh et al., 2004 (26) | 325 | ATL | 10 | Engel 1 | 41% |
| Urbach et al., 2004 (56) | 209 | SAH | 2 | Engel 1A | 73% |
| Jeong et al., 2005 (19) | 227 | ATL | 5 | Engel 1 | 75% |
| Spencer et al., 2005 (49) | 339 | AMTL | 5 | Seizure freedom | 69% |
| Schmeiser et. al, 2017 (44) | 458 | ATL+SAH | 5 | Engel 1 | 68.1% |
| Erdem et al., current study | 238 | ATL+AH | 16 | Engel 1 | 90.7% |

***SAH:** Selective amygdalo-hippocampectomy, **ATL:** Anterior temporal lobectomy, **AMTL:** Anteromedial temporal lobectomy.*

## ■ DISCUSSION

Many surgical approaches have been practiced in the treatment of medically intractable epilepsy. One of the most effective approaches is resective surgery, in which the response to surgical treatment is very high, especially in medically intractable TLE. Despite the frequent occurrence of TLE and its treatment-resistant nature, it has a high seizure-free rate with very good response to surgery and the surgical risks are relatively low (4,52). However, in the case of resective surgeries which provide the best results in terms of seizure-free rate and neuropsychological outcome, the resection approach and size have not been established yet (4,18,30,45,58).

In the early days of temporal lobe surgery for the treatment of epilepsy, it was common practice to spare the hippocampus to prevent memory impairment (27,46). However, Penfield et al. observed that sparing the mesial temporal structures was associated with poor seizure control (38-40). The primary purpose of temporal lobe surgery is to get rid of seizures without causing neurological or cognitive dysfunction. In TLE surgery, the mesial temporal structures were removed with varying degrees of lateral neocortical resection. Different temporal lobectomy surgical techniques have also been reported for this (1).

The standard ATL consists of en bloc resection or resection of individual lateral and mesial temporal structures. The removal of the lateral temporal structures provides a better visualization of the mesial structures and allows the hippocampus to be removed in block. It should be noted that the resection of amygdaloid nucleus does not extend to the globus pallidus in the superior and medial directions. Since no clear boundary is established between the amygdala and the globus pallidus, the anatomical locations for amygdala resection vary between surgeons. Wieser and Yasargil advocate the use of the insular circular sulcus and uncus to avoid entering the globus pallidus (61). Based on the anatomical dissection study, Wen et al. found that a line connecting the inferior choroidal point and proximal MCA can define the upper limit of the resection to the amygdale (57). In the cadaver study, where Tubbs et al. examined the line connecting the AChA and MCA bifurcation, it was found that using this line to remove the amygdala did not damage the striatum (54).

The anteromedial temporal resection technique, which was developed by Spencer, is used to maintain the function of the lateral temporal cortex and access the mesial temporal structures from the temporal pole corridor (48). In this technique, approximately 5–6 cm of the temporal lobe is exposed. The cortical incision starts at 3–3.5 cm from the temporal tip at T2 and bends toward T3 and the temporal base. T1 is usually protected. The temporal tip is removed laterally toward the temporal horn. The temporal horn is entered, followed by the resection of the uncus and amygdala. Resection of the hippocampus and parahippocampal gyrus is performed from anterior to posterior.

The transcortical selective amygdalo-hippocampectomy (SAH) was introduced by Niemeyer in 1958 and was originally called "transventricular amygdalo-hippocampectomy" (32). Niemeyer used a cortical incision along T2 to reach the mesial temporal structures. Later, Olivier changed this technique to include the resection of the anterior part of T1 (33,34).

Wieser and Yasargil introduced the transsylvian SAH approach to resect mesial temporal structures using the sylvian fissure corridor without sacrificing the neighboring temporal neocortex (61,62).

Shimizu et al. explained the minimal resection of T3 by removing the zygomatic arch and accessing the mesial temporal structures using a zygomatic approach (47). Subtemporal SAH was first described in 1993 by Hori et al. (17). This technique involves the removal of the fusiform gyrus to reach the temporal horn and the cutting of the tentorium to minimize retraction on the temporal lobe. Park et al. reported a modification of the subtemporal approach through transparahippocampal entry while preserving the fusiform gyrus (36). Later, Hori et al. modified the subtemporal approach, preferring the retrolabyrinthine presigmoid transpetrosal approach to resect the mesial temporal structures (16). Miyamoto et al. performed amygdalo-hippocampectomy using the combined subtemporal and transventricular-transchoroidal fissure approach (28). In general, the rationale for using this approach is to avoid an incision in the temporal stem, minimize visual field deficits, and preserve the temporal neocortex. However, this approach carries the risk of injury to the vein of Labbe (due to temporal lobe retraction), and the inability to expose the amygdala and uncus restricts resection. Although the resection of the anterior parts such as the uncus and the amygdala is quite difficult, the subtemporal approach provides an excellent overview of the posterior hippocampal/mesiotemporal area.

It has been reported that the paramedian-supraserebellar transtentorial approach, which has been proposed as an alternative surgical approach for accessing the mediobasal temporal region, may also be a suitable alternative for the selective removal of the parahippocampal gyrus, hippocampus, and amygdala in TLE patients due to hippocampal sclerosis (55). Moreover, this approach for TLE surgery has been reported to have no consequences (9).

Temporal disconnection is advocated as an alternative surgical procedure to avoid complications while providing a level of seizure control comparable to traditional surgery. Hippocampal transection, which requires multiple subpial transection logic (although the number of patients and follow-up is limited), has been reported to minimize memory dysfunction after hippocampectomy (6,51). Stereotactic radiosurgery is used among the treatment options of mesial temporal epilepsy and has been reported that it may be useful (37).

Changes in temporal lobe resective surgery are based on the use of ECoG and cortical mapping (to avoid functional deficits) for the resection of the epileptogenic region or the resection of the seizure onset such as SAH (21). It has been suggested that the amount of resected mesial temporal tissue correlates with a successful surgery (3,31). Residual tissue is a known risk factor for seizure recurrence, and a second operation should be considered in patients who continue to have seizures (10). The effectiveness of residual hippocampal resection and positive results after SAH suggest that a comprehensive resection of the hippocampus may be necessary for optimal seizure control (10). In addition, it has been suggested that lesionectomy will contribute additionally to seizure control in patients with structural lesions (15,31).

The results of the selected studies using different surgical techniques and the results of the present study are presented in Table V. So, far, the literature does not show any significant difference in terms of seizure-free rates in patients who underwent SAH or ATL surgery for TLE (Table V). To date, no randomized controlled trial has been conducted to evaluate and compare surgical approaches of SAH and ATL for TLE treatment. However, as a result of the compilation of various studies, it has been reported that there is not much Class I evidence that relates the resection type and the degree of resection of the mesial temporal lobe structures with seizure outcome (45). In addition, seizure recurrence was observed in patients undergoing SAH, and freedom from seizure was achieved by adding ATL with reoperation (10). This supports our hypothesis that ATL + AH can be superior in terms of freedom from seizure. Moreover, it has been reported that SAH has a similar seizure outcome but possibly better cognitive results compared to ATL (45,58). However, another study has been reported that there was no significant difference between ATL and SAH in terms of seizures and neuropsychological outcomes (30). Although our study was not a comparative study between ATL and SAH, no significant neuropsychological morbidity was observed among the patients after surgery (Table III).

The analysis of the studies published from 1992 to 2018 supports the conclusion that Schramm generally tends to have more neuropsychological deficits in ATL than SAH surgery. However, the heterogeneity of the studies and the absence of a randomized controlled trial comparing the two surgical techniques make it impossible to make precise decisions on the neuropsychological effect (Table V). With a retrospective study of 432 patients, Schmeiser et al. evaluated the seizure outcomes, neuropsychological outcomes, and complications of the standard ATL, anterior temporal or key hole resection, extended lesionectomy, and trans-sylvian and subtemporal SAH. No significant difference was found in terms of seizure outcomes, neuropsychological outcomes, and the rates of complications between different surgical approaches in patients (44). They reported the seizure-free rate (Engel I) to be 72.9% during the 1-year follow-up after surgery (44). Besides the mesial part of the temporal lobe, it has been reported that the removal of the neocortex will not lead to better seizure control (14). However, the amygdaloid nuclear complex, which we consider to be responsible in the pathogenesis of TLE, led us to the integration of anterior temporal polectomy into our surgery (10).

Considering the morbidity of patients who underwent surgery for TLE, visual field and memory defects have an important place (24,25,29,53). When complications in our series were examined, it was found that the visual field defect was in similar proportions with other series (25). Even if patients did not undergo surgery for TLE, memory defects can still be observed (27,35,46). In our series, it was observed that the new development of memory defect or the worsening in memory defect was similar to that in other series (24,29,53).

However, a limitation of our study is that it was designed based on a standard surgical technique. Therefore, it is possible to compare the seizure-free rates and neuropsychological results only with the literature. Considering the seizure-free rates and all the complications/morbidity rates in our series, we believe that it is important to select the appropriate patients and to integrate the surgical technique nuances with the micro-neuroanatomic details. Considering these results and our 29 years of epilepsy surgery experience and seizure-free outcomes, we believe that higher seizure-free rate will be achieved with ATL+AH.

## CONCLUSION

Considering the different approaches and surgical techniques proposed, we believe that the surgical nuances which we emphasized will provide a high seizure-free rate with acceptable complication rates. Although the findings of this study are useful, future comparative multi-center studies are needed.

As with any surgery, the integration of surgical nuances and micro-neuroanatomic details will improve the surgical results in mesial TLE surgery.

## REFERENCES


1. Al-Otaibi F, Baeesa SS, Parrent AG, Girvin JP, Steven D: Surgical techniques for the treatment of temporal lobe epilepsy. Epilepsy Res Treat 2012:374848, 2012
2. Awad IA, Katz A, Hahn JF, Kong AK, Ahl J, Luders H: Extent of resection in temporal lobectomy for epilepsy. I. Interobserver analysis and correlation with seizure outcome. Epilepsia 30:756-762, 1989
3. Beghi E, Tognoni G: Prognosis of epilepsy in newly referred patients: A multicenter prospective study of the effects of monotherapy on the long-term course of epilepsy. Collaborative Group for the Study of Epilepsy. Epilepsia 33:45-51, 1992
4. Boling WW: Surgical considerations of intractable mesial temporal lobe epilepsy. Brain Sci 8(2): 35, 2018
5. Cascino GD: Intractable partial epilepsy: Evaluation and treatment. Mayo Clin Proc 65:1578-1586, 1990
6. Chabardes S, Minotti L, Hamelin S, Hoffmann D, Seigneuret E, Carron R, Krainik A, Grand S, Kahane P, Benabid AL: Temporal disconnection as an alternative treatment for intractable temporal lobe epilepsy: Techniques, complications and results. Neurochirurgie 54:297-302, 2008
7. Chadwick D: Epilepsy. J Neurol Neurosurg Psychiatry 57:264-277, 1994
8. Engel J Jr, Van Ness PC, Rasmussen TB, Ojemann LM: Outcome with respect to epileptic seizures. In: Engel J Jr (ed), Surgical Treatment of the Epilepsies, 2 ed, Raven Press, 1993: 609-621
9. Erdem A: Letter: The paramedian supracerebellar-transtentorial selective amygdalohippocampectomy for mediobasal temporal epilepsy. Oper Neurosurg (Hagerstown) 15:E33, 2018
10. Erdem A, Kahilogullari G, Erbas YC, Karatas A, Bilir E: Reoperation of a recurrent temporal lobe epilepsy: A technical case report. Surg Neurol 64 Suppl 2:S102-105, 2005
11. Erdem A, Yasargil G, Roth P: Microsurgical anatomy of the hippocampal arteries. J Neurosurg 79:256-265, 1993
12. Germano IM, Poulin N, Olivier A: Reoperation for recurrent temporal lobe epilepsy. J Neurosurg 81:31-36, 1994
13. Gomceli YB, Erdem A, Bilir E, Kutlu G, Kurt S, Erden E, Karatas A, Erbas C, Serdaroglu A: Surgery in temporal lobe epilepsy patients without cranial MRI lateralization. Acta Neurol Belg 106:9-14, 2006
14. Hemb M, Palmini A, Paglioli E, Paglioli EB, Costa da Costa J, Azambuja N, Portuguez M, Viuniski V, Booij L, Nunes ML: An 18-year follow-up of seizure outcome after surgery for temporal lobe epilepsy and hippocampal sclerosis. J Neurol Neurosurg Psychiatry 84:800-805, 2013
15. Hirfanoglu T, Serdaroglu A, Kurt G, Erdem A, Capraz I, Bilir E, Vural O, Ucar M, Oner AY, Onal B, Akdemir O, Atay O, Arhan E, Aydin K: Outcomes of resective surgery in children and adolescents with focal lesional epilepsy: The experience of a tertiary epilepsy center. Epilepsy Behav 63:67-72, 2016
16. Hori T, Kondo S, Takenobu A, Hirao J, Kohaya N, Takeuchi H, Watanabe T: Retrolabyrinthine presigmoid transpetrosal approach for selective subtemporal amygdalohippocampectomy. Neurol Med Chir (Tokyo) 39:214-224; discussion 224-225, 1999
17. Hori T, Tabuchi S, Kurosaki M, Kondo S, Takenobu A, Watanabe T: Subtemporal amygdalohippocampectomy for treating medically intractable temporal lobe epilepsy. Neurosurgery 33:50-56; discussion 56-57, 1993

18. Hu WH, Zhang C, Zhang K, Meng FG, Chen N, Zhang JG: Selective amygdalohippocampectomy versus anterior temporal lobectomy in the management of mesial temporal lobe epilepsy: A meta-analysis of comparative studies. J Neurosurg 119:1089-1097, 2013
19. Jeong SW, Lee SK, Hong KS, Kim KK, Chung CK, Kim H: Prognostic factors for the surgery for mesial temporal lobe epilepsy: Longitudinal analysis. Epilepsia 46:1273-1279, 2005
20. Jutila L, Immonen A, Mervaala E, Partanen J, Partanen K, Puranen M, Kalviainen R, Alafuzoff I, Hurskainen H, Vapalahti M, Ylinen A: Long term outcome of temporal lobe epilepsy surgery: Analyses of 140 consecutive patients. J Neurol Neurosurg Psychiatry 73:486-494, 2002
21. Karatas A, Erdem A, Savas A, Kutlu G, Yagmurlu B, Erden I, Bilir E: Identification and removal of an epileptogenic lesion using Ictal-EEG, functional-neuronavigation and electrocorticography. J Clin Neurosci 11:343-346, 2004
22. Kutlu G, Bilir E, Erdem A, Gomceli YB, Leventoglu A, Kurt GS, Karatas A, Serdaroglu A: Temporal lobe ictal behavioral patterns in hippocampal sclerosis and other structural abnormalities. Epilepsy Behav 6:353-359, 2005
23. Kuzniecky R, Burgard S, Faught E, Morawetz R, Bartolucci A: Predictive value of magnetic resonance imaging in temporal lobe epilepsy surgery. Arch Neurol 50:65-69, 1993
24. Lutz MT, Clusmann H, Elger CE, Schramm J, Helmstaedter C: Neuropsychological outcome after selective amygdalohippocampectomy with transsylvian versus transcortical approach: A randomized prospective clinical trial of surgery for temporal lobe epilepsy. Epilepsia 45:809-816, 2004
25. Mathon B, Navarro V, Bielle F, Nguyen-Michel VH, Carpentier A, Baulac M, Cornu P, Adam C, Dupont S, Clemenceau S: Complications after surgery for mesial temporal lobe epilepsy associated with hippocampal sclerosis. World Neurosurg 102:639-650 e632, 2017
26. McIntosh AM, Kalnins RM, Mitchell LA, Fabinyi GC, Briellmann RS, Berkovic SF: Temporal lobectomy: Long-term seizure outcome, late recurrence and risks for seizure recurrence. Brain 127:2018-2030, 2004
27. Milner B, Klein D: Loss of recent memory after bilateral hippocampal lesions: memory and memories-looking back and looking forward. J Neurol Neurosurg Psychiatry 87:230, 2016
28. Miyamoto S, Kataoka H, Ikeda A, Takahashi J, Usui K, Takayama M, Satow T, Hashimoto N: A combined subtemporal and transventricular/transchoroidal fissure approach to medial temporal lesions. Neurosurgery 54:1162-1167; discussion 1167-1169, 2004
29. Morino M, Uda T, Naito K, Yoshimura M, Ishibashi K, Goto T, Ohata K, Hara M: Comparison of neuropsychological outcomes after selective amygdalohippocampectomy versus anterior temporal lobectomy. Epilepsy Behav 9:95-100, 2006
30. Nascimento FA, Gatto LA, Silvado C, Mader-Joaquim MJ, Moro MS, Araujo JC: Anterior temporal lobectomy versus selective amygdalohippocampectomy in patients with mesial temporal lobe epilepsy. Arq Neuropsiquiatr 74:35-43, 2016
31. Nayel MH, Awad IA, Luders H: Extent of mesiobasal resection determines outcome after temporal lobectomy for intractable complex partial seizures. Neurosurgery 29:55-60; discussion 60-51, 1991
32. Niemeyer P: The transventricular amygdalohippocampectomy in temporal lobe epilepsy. In: Baldwin M, Baily P (eds), Temporal Lobe Epilepsy, Springfield: Charles C. Thomas, 1958: 461-482
33. Olivier A: Surgical techniques in temporal lobe epilepsy. Clin Neurosurg 44:211-241, 1997
34. Olivier A: Transcortical selective amygdalohippocampectomy in temporal lobe epilepsy. Can J Neurol Sci 27 Suppl 1:S68-76; discussion S92-96, 2000
35. Ozkara C, Hanoglu L, Keskinkilic C, Yeni N, Aysal F, Uzan M, Ozyurt E, Karaagac N: Memory in patients with drug-responsive mesial temporal lobe epilepsy and hippocampal sclerosis. Epilepsia 45:1392-1396, 2004
36. Park TS, Bourgeois BF, Silbergeld DL, Dodson WE: Subtemporal transparahippocampal amygdalohippocampectomy for surgical treatment of mesial temporal lobe epilepsy. Technical note. J Neurosurg 85:1172-1176, 1996
37. Parrent AG, Blume WT: Stereotactic amygdalohippocampotomy for the treatment of medial temporal lobe epilepsy. Epilepsia 40:1408-1416, 1999
38. Penfield W, Baldwin M: Temporal lobe seizures and the technic of subtotal temporal lobectomy. Ann Surg 136:625-634, 1952
39. Penfield W, Flanigin H: The surgical therapy of temporal lobe seizures. Trans Am Neurol Assoc 51:146-149, 1950
40. Penfield W, Milner B: Memory deficit produced by bilateral lesions in the hippocampal zone. AMA Arch Neurol Psychiatry 79:475-497, 1958
41. Radhakrishnan K, So EL, Silbert PL, Cascino GD, Marsh WR, Cha RH, O'Brien PC: Prognostic implications of seizure recurrence in the first year after anterior temporal lobectomy. Epilepsia 44:77-80, 2003
42. Salanova V, Markand O, Worth R: Longitudinal follow-up in 145 patients with medically refractory temporal lobe epilepsy treated surgically between 1984 and 1995. Epilepsia 40:1417-1423, 1999
43. Scheffer IE, Berkovic S, Capovilla G, Connolly MB, French J, Guilhoto L, Hirsch E, Jain S, Mathern GW, Moshe SL, Nordli DR, Perucca E, Tomson T, Wiebe S, Zhang YH, Zuberi SM: ILAE classification of the epilepsies: Position paper of the ILAE Commission for Classification and Terminology. Epilepsia 58:512-521, 2017
44. Schmeiser B, Wagner K, Schulze-Bonhage A, Mader I, Wendling AS, Steinhoff BJ, Prinz M, Scheiwe C, Weyerbrock A, Zentner J: Surgical treatment of mesiotemporal lobe epilepsy: which approach is favorable? Neurosurgery 81:992-1004, 2017
45. Schramm J: Temporal lobe epilepsy surgery and the quest for optimal extent of resection: A review. Epilepsia 49:1296-1307, 2008
46. Scoville WB, Milner B: Loss of recent memory after bilateral hippocampal lesions. J Neurol Neurosurg Psychiatry 20:11-21, 1957
47. Shimizu H, Suzuki I, Ishijima B: Zygomatic approach for resection of mesial temporal epileptic focus. Neurosurgery 25:798-801, 1989

48. Spencer DD, Spencer SS, Mattson RH, Williamson PD, Novelly RA: Access to the posterior medial temporal lobe structures in the surgical treatment of temporal lobe epilepsy. Neurosurgery 15:667-671, 1984
49. Spencer SS, Berg AT, Vickrey BG, Sperling MR, Bazil CW, Shinnar S, Langfitt JT, Walczak TS, Pacia SV, Multicenter Study of Epilepsy S: Predicting long-term seizure outcome after resective epilepsy surgery: The multicenter study. Neurology 65:912-918, 2005
50. Sperling MR, O'Connor MJ, Saykin AJ, Plummer C: Temporal lobectomy for refractory epilepsy. JAMA 276:470-475, 1996
51. Sunaga S, Morino M, Kusakabe T, Sugano H, Shimizu H: Efficacy of hippocampal transection for left temporal lobe epilepsy without hippocampal atrophy. Epilepsy Behav 21:94-99, 2011
52. Tanriverdi T, Ajlan A, Poulin N, Olivier A: Morbidity in epilepsy surgery: An experience based on 2449 epilepsy surgery procedures from a single institution. J Neurosurg 110:1111-1123, 2009
53. Tanriverdi T, Olivier A: Cognitive changes after unilateral cortico-amygdalohippocampectomy unilateral selective-amygdalohippocampectomy mesial temporal lobe epilepsy. Turk Neurosurg 17:91-99, 2007
54. Tubbs RS, Miller JH, Cohen-Gadol AA, Spencer DD: Intraoperative anatomic landmarks for resection of the amygdala during medial temporal lobe surgery. Neurosurgery 66:974-977, 2010
55. Ture U, Harput MV, Kaya AH, Baimedi P, Firat Z, Ture H, Bingol CA: The paramedian supracerebellar-transtentorial approach to the entire length of the mediobasal temporal region: An anatomical and clinical study. Laboratory investigation. J Neurosurg 116:773-791, 2012
56. Urbach H, Hattingen J, von Oertzen J, Luyken C, Clusmann H, Kral T, Kurthen M, Schramm J, Blumcke I, Schild HH: MR imaging in the presurgical workup of patients with drug-resistant epilepsy. AJNR Am J Neuroradiol 25:919-926, 2004
57. Wen HT, Rhoton AL Jr, de Oliveira E, Cardoso AC, Tedeschi H, Baccanelli M, Marino R Jr: Microsurgical anatomy of the temporal lobe: Part 1: Mesial temporal lobe anatomy and its vascular relationships as applied to amygdalohippocampectomy. Neurosurgery 45:549-591; discussion 591-542, 1999
58. Wendling AS, Hirsch E, Wisniewski I, Davanture C, Ofer I, Zentner J, Bilic S, Scholly J, Staack AM, Valenti MP, Schulze-Bonhage A, Kehrli P, Steinhoff BJ: Selective amygdalohippocampectomy versus standard temporal lobectomy in patients with mesial temporal lobe epilepsy and unilateral hippocampal sclerosis. Epilepsy Res 104:94-104, 2013
59. Wiebe S, Blume WT, Girvin JP, Eliasziw M, Effectiveness, Efficiency of Surgery for Temporal Lobe Epilepsy Study G: A randomized, controlled trial of surgery for temporal-lobe epilepsy. N Engl J Med 345:311-318, 2001
60. Wieser HG, Blume WT, Fish D, Goldensohn E, Hufnagel A, King D, Sperling MR, Luders H, Pedley TA, Commission on Neurosurgery of the International League Against E: ILAE Commission Report. Proposal for a new classification of outcome with respect to epileptic seizures following epilepsy surgery. Epilepsia 42:282-286, 2001
61. Wieser HG, Yasargil MG: Selective amygdalohippocampectomy as a surgical treatment of mesiobasal limbic epilepsy. Surg Neurol 17:445-457, 1982
62. Yasargil MG, Teddy PJ, Roth P: Selective amygdalo-hippocampectomy. Operative anatomy and surgical technique. Adv Tech Stand Neurosurg 12:93-123, 1985