Functional Anterior Temporal Lobectomy for Temporal Lobe Epilepsy: A Novel, Alternative, and Less Invasive Therapy

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BACKGROUND: Anterior temporal lobectomy is the most effective treatment for intractable temporal lobe epilepsy (TLE). However, patients are reluctant to choose this surgery for fear of risks after large frontotemporal craniotomy, and epileptologists likewise have a cautious attitude because of surgical trauma. Functional anterior temporal lobectomy (FATL) is a minimally invasive surgery procedure for addressing the above concerns.

OBJECTIVE: To report preliminary data on this procedure and its safety and efficacy for treating TLE.

METHODS: This consecutive case series study was conducted between October 2020 and September 2021. Patients with TLE underwent FATL by minicraniotomy with a diameter of 3 cm. Surgery duration, postoperative complications, and seizure control are described herein. Seizure outcomes were classified using Engel classifications.

RESULTS: A total of 25 patients undergoing FATL for TLE were enrolled. The median epilepsy duration was 8 years. The median surgery duration was 165 min. The median blood loss was 100 mL. The median postoperative hospital stay was 8 days. No deaths occurred after surgery. Only 1 patient presented with a cerebrospinal fluid disorder that was successfully treated using a ventriculoperitoneal shunt. At the last follow-up, 23 patients (92%) were seizure-free (Engel-Ia), 1 patient remained substantially improved (Engel-II), and 1 patient obtained worthwhile seizure reduction (Engel-III).

CONCLUSION: Our pilot study suggests that FATL is a viable surgical therapy for TLE. This method has the advantages of minimal invasiveness and high seizure-free rate. A controlled trial is warranted to verify the efficacy and safety of FATL comparing with anterior temporal lobectomy.

KEY WORDS: Temporal lobe epilepsy, Anterior temporal lobectomy, Functional anterior temporal lobectomy, Minimally invasive surgery

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Anterior temporal lobectomy (ATL), consisting of an anterior temporal corticotomy followed by removal of the mesial temporal structures, was first reported by Penfield in the 1950s.[1,2] ATL for temporal lobe epilepsy (TLE) has since become the standard surgical technique most commonly performed at most epilepsy centers.[3,4] However, ATL remains underutilized worldwide.[5,6] The annual rate with respect to performing ATL for TLE likewise declined by >65% between 2006 and 2010 in the United States.[6] The likely reasons for these declines in ATL utilization are unclear and speculative. One important factor may be that ATL is performed using large frontotemporal craniotomy, which carries the risk of potential complications. Scar wounds, focal hair loss, and muscular atrophy following frontotemporal craniotomy result in a poor cosmetic appearance. ATL likewise creates a large cavity because of temporal lobe resection, risking brain shifts (**eFigure 1A and 1B, Supplemental Digital Content**, http://links.lww.com/ONS/A790 and http://links.lww.com/ONS/A791), subdural collections, and cerebrospinal fluid (CSF) leakage. During

ABBREVIATIONS: ATL, anterior temporal lobectomy; **CSF,** cerebrospinal fluid; **FATL,** functional anterior temporal lobectomy; **PCA,** posterior cerebral artery; **PET,** positron emission tomography; **TLD,** temporal lobe disconnection; **TLE,** temporal lobe epilepsy.

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preoperative counseling, patients with TLE often inquire as to whether this surgical therapy is minimally invasive. Fear of risks after large craniotomy causes patients to be reluctant to choose ATL. Epileptologists are also reluctant to refer patients with TLE to surgical centers.

Functional anterior temporal lobectomy (FATL) using minicraniotomy has been established as a viable alternative to ATL for the treatment of TLE in our center (as of 2020). Herein, we preliminarily report the clinical outcomes of FATL as a novel surgical procedure for TLE.

METHODS

Participants

We retrospectively reviewed consecutively presenting patients undergoing FATL at our epilepsy surgery center between October 20, 2020, and September 2, 2021. All FATL procedures were performed by a single surgeon. Inclusion criteria included patients of all ages and sexes, unilateral TLE, written informed consent, and good compliance. Exclusion criteria included tumors in the temporal lobe, bilateral TLE, significant comorbidities (eg, progressive neurological disorders, active psychosis, and drug abuse), previous epilepsy surgery, and poor compliance. The last follow-up for all enrolled patients was performed in December 2021. The data used for this study, although not available in a public repository, will be made available to other researchers on reasonable request.

Preoperative Evaluations

Patients underwent the following presurgical evaluations: (1) long-term video electroencephalography monitoring with the use of scalp electrodes using the international 10-20 system for interictal and ictal events; (2) 3-T MRI, involving T1-weighted, T2-weighted, and fluid-attenuated inversion-recovery sequences in the 3-dimensional scanning mode with a 1-mm slice thickness and without an intervening gap along the long axis of the hippocampus; and (3) positron emission tomography (PET) images for evaluating metabolism within the temporal lobe. Detailed evaluations of typical TLE is presented in **eFigure 2A-2G**, **Supplemental Digital Content**, http://links.lww.com/ONS/A792, http://links.lww.com/ONS/A793, http://links.lww.com/ONS/A794, http://links.lww.com/ONS/A795, http://links.lww.com/ONS/A796, http://links.lww.com/ONS/A797, and http://links.lww.com/ONS/A798. Neuropsychological tests were also performed before surgery, including Rey auditory verbal learning test (0-15 scores) for verbal memory, brief visuospatial memory test-revised (0-12 scores) for visuospatial memory, and Boston naming test (30 items) and verbal fluency test (animals in 1 minute) for language. Written informed consent was provided by patients with TLE or their proxies before surgery. The patient consented to publication of his/her images. This study was approved by the ethics review board at our hospital.

Surgical Procedure

Surgical trajectories are depicted in Figures 1A-1C. FATL includes 3 main steps: opening the temporal horn, resecting the mesial temporal structures, and disconnecting the lateral temporal cortex. Under general anesthesia, patients were placed in the supine position with their head contralaterally rotated by 30° and fixed on a Mayfield clamp. A 3D model of the bone flap was printed before surgery based on MRI data (Figures 2A-2B). 3D model is an assisted and convenient tool for craniotomy planning. The circle with 3 cm in diameter represents the area of bone flap. The center of circle is about 4 cm posterior to the temporal pole. There are sylvian fissure, superior temporal gyrus, superior temporal sulcus, and partial middle temporal gyrus in the circle. 3D model is helpful for minicraniotomy, increasing the effective exposure area.

Then, a slight curve incision approximately 6 cm in length was marked in the temporal region beginning from the zygomatic arch (Figure 2C). A temporal craniotomy through the small bone window (with a diameter of approximately 3 cm) was performed (Figure 2D). The dura was opened through a cross-shaped incision. The temporal horn was accessed approximately 4 cm posterior to the temporal pole by dissecting the superior temporal gyrus under microscopy (Figure 2E). The head of the temporal horn was exposed (Figure 2F). The head, body, and tail of the hippocampus are shown in Figure 2G. The amygdala was exposed and resected. The parahippocampal gyrus and the hippocampus were operated by en bloc resection. Subpial suction was performed for protecting the vessels and nerves (Figure 2H-2I).

Finally, temporal lobotomy was easily performed because of the large view after the brain shift. The lateral temporal lobe was obviously collapsed and displaced at a distance of 1.5 cm from the bone window (Figure 2J). The loss of CSF was the one hand and on the other hand was due to reduced volume of the temporal lobe after amygdalohippocampectomy and the removal of the temporal stem. A large operating space was made for facilitating the temporal disconnection. The temporal stem was divided to isolate the superior temporal gyrus (Figure 2K). The lateral posterior temporal lobotomy was located ≤5 cm from the temporal pole (Figure 2L). Our surgical technique is shown in Video.

Outcomes Measures

Brain MRI was performed at the third month after surgery. Neuropsychological tests were performed yearly after surgery. Postoperative complications and permanent morbidities were recorded. We categorized seizure outcomes according to Engel classifications: class I, free of disabling seizures (Ia, completely seizure-free); class II, rare disabling seizures (almost seizure-free at less than 3 seizure days per year); class III, worthwhile improvement or a greater than 50% reduction in seizure frequency; and class IV, no worthwhile improvement or a less than 50% reduction in seizure frequency.[7]

Acute postoperative seizures were defined as seizures occurring in the first postoperative week.[8] Complications were defined according to the criteria specified in the study by Bjellvi et al.[9] Complication severity was graded as minor if the complication resolved within 3 months and was graded as major if it lasted for longer than 3 months and affected activities of daily living.

RESULTS

Patient Characteristics

Of the 25 patients with TLE enrolled in this study, 22 (88%) were adults (18 years or older). Table 1 shows the outlined characteristics for all patients. The median age at surgery was 28 years, the median age at first seizure was 18.8 years, and the median epilepsy duration was 8 years. In presurgical evaluations, MRI demonstrated that 22 patients had positive findings in the temporal lobe, and PET demonstrated that 21 patients had hypometabolism in the unilateral temporal lobe.

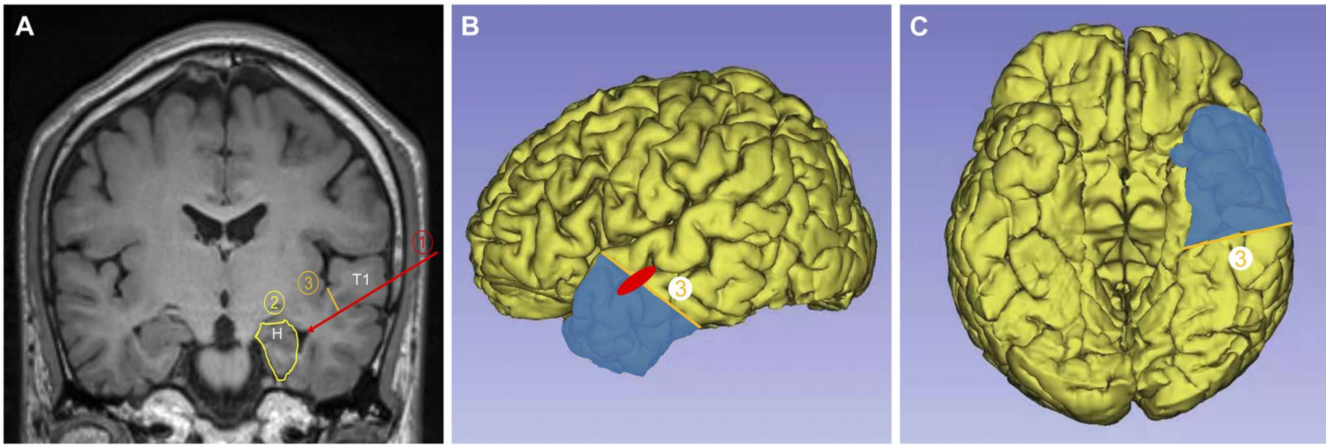

FIGURE 1. *Diagram of functional anterior temporal lobectomy. Circle 1 (red line) represents the trajectory of access to the temporal horn by dissecting the T1. Circle 2 (yellow line) represents amygdalohippocampectomy. Circle 3 (orange line) represents the disconnection of the lateral temporal lobe (blue region).* **A**, *coronary scan.* **B**, *lateral view.* **C**, *inferior view. H, hippocampus; T1, superior temporal gyrus.*

Surgical Outcomes

Table 2 shows surgical outcomes of FATL. Seventeen patients underwent left FATL, and 8 underwent right FATL. The median surgery duration was 165 minutes (range, 120-270 minutes). The median blood loss was 100 mL. Acute postoperative seizures were observed in 1 patient. The median postoperative hospital stay was 8 days. No neurological signs of infarction or swelling of the disconnected tissue occurred postoperatively. No deaths occurred after FATL. The mesial temporal structures were completely resected and lateral temporal lobe was completely disconnected (Figure 3A-3C). The cosmetic appearance of the wound was rigorously evaluated for all patients (Figure 3D and 3E). All patients were satisfied with the surgical procedure.

Complications were recorded for 1 patient only. CSF disorders, including hydrocephalus, subdural effusion, and CSF leakage, were found in a female patient 1 month after FATL (Figure 4A and 4B). The intracranial pressure was 350 mmH_2O as measured by lumbar puncture. External lumbar drainage of the CSF was performed (less than 200 mL per day for 12 days). The patient's CSF leakage was cured. Hydrocephalus and subdural effusion were unimproved at 2 months after FATL (Figure 4C). The patient's walking instability gradually worsened. Intracranial pressure was 250 mmH_2O as assessed by lumbar puncture. A ventriculoperitoneal shunt was performed. Hydrocephalus was alleviated and subdural effusion disappeared at 1 month after the shunt (Figure 4D). This complication was major according to established severity grades, with a major complication rate of 4%.

Seizure Outcomes

All patients were followed up for a minimum period of 4 months after surgery. The median follow-up duration was 9 months (range, 4-14.6 months). At the last follow-up, 23/25 patients (92%) were seizure-free (Engel class Ia), 4% of the patients (1/25) were classified as Engel class II, and 4% of the patients (1/25) were classified as Engel class III (Table 2). The percentage of seizure freedom over time is estimated in **eFigure 3**, **Supplemental Digital Content**, http://links.lww.com/ONS/A799.

Because of short follow-up, neuropsychological tests were performed in 6 patients at 1 year after FATL. Slight declines were observed without significant difference from the baseline. Mean changes of Rey auditory verbal learning test delayed recall, brief visuospatial memory test-revised delayed recall, Boston naming test, and verbal fluency test from the baseline were −1.1, −0.5, −2.7, and −1.2, respectively.

DISCUSSION

ATL as a Traditional Surgery for TLE

ATL is a standard therapy and one of the most successful surgeries for the treatment of TLE.[4,10] However, ATL is performed using large frontotemporal craniotomy, thus causing potential risks. Some degree of complications remain an unavoidable consequence of this surgical procedure. Nevertheless, neurological deficits after this procedure have decreased from 41.8% to 5.2%, and wound infections or meningitis have decreased from 2.5% to 1.1% according to a recent study.[11] Thirty-day complications after temporal lobectomy for intractable epilepsy included a mortality rate of 1.4%, a major complication rate of 6.5%, and a readmission rate of 11%.[12] Therefore, minimally invasive surgical procedures for TLE have become a recent trend within epilepsy surgery.

Temporal Lobe Disconnection (TLD) as an Alternative to ATL

The concept of isolating the area of the brain that includes the epileptic focus (as compared with resection) is well known.[13,14] Functional hemispherectomy involves the extensive disconnection

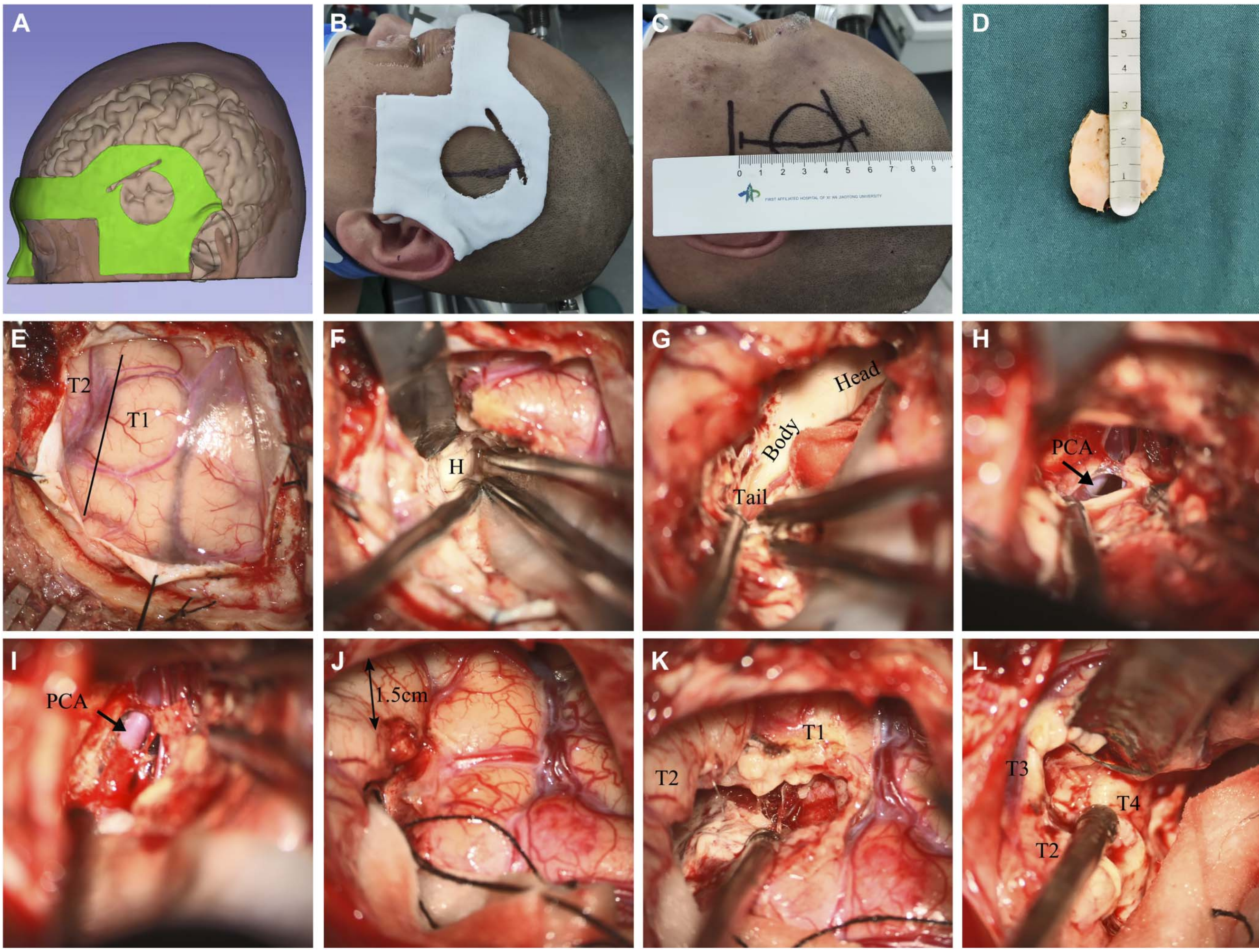

FIGURE 2. *Surgical technique of functional anterior temporal lobectomy.* **A**, *3D model of the minimal craniotomy.* **B**, *Printed model of bone window.* **C**, *Skin incision.* **D**, *Small bone flap.* **E** *and* **F**, *Opening the temporal horn.* **G-I**, *Resecting mesial temporal structures including the hippocampus, amygdala, and parahippocampal gyrus.* **J-L**, *Disconnecting the lateral temporal lobe cortex. H, hippocampus; T1, superior temporal gyrus; T2, middle temporal gyrus; T3, inferior temporal gyrus; T4, fusiform gyrus; PCA, posterior cerebral artery.*

of unilateral hemispherical damage, in contrast to the complete removal of the hemisphere (ie, anatomic hemispherectomy).[15]

TLD for nonlesional TLE was performed by Chabardès et al[16] from 1998 to 2006. A total of 47 patients underwent TLD through a 5-cm circular craniotomy. At the 2-year follow-up, 85% of the patients were seizure-free (Engel I), 26 (58%) of whom presented as Engel class Ia. Recently, Massager et al[17] reported long-term outcomes after TLD for 45 patients with nonlesional mesial TLE. In this study, 30 patients (67%) were completely seizure-free at the last follow-up. Above studies suggest that TLD is an alternative surgical technique to resection for TLE. The main advantage of this procedure is that disconnection prevents brain shift and subsequent subdural collections, shortens the surgery duration, and allows for a smaller craniotomy. However, the major drawback of TLD is the narrowed corridor of the approach, increasing the probability of incomplete disconnection of the anterior temporal lobe. Therefore, the prevalence of TLD is limited and, to the best of our knowledge, has only been reported in several studies.[16-18] Nevertheless, these technical reports on TLD provide a reference for a less invasive procedure in the future.

FATL as a Novel, Less Invasive Surgery for TLE

Minimally invasive surgery is a trend within less invasive procedures, generating fewer complications and good seizure outcomes. FATL is a novel surgical approach for TLE with the obvious advantage of minimal invasion; this is a modified technique based on the combination of ATL and TLD. FATL follows the principle of functional isolation of the temporal lobe through

TABLE 1. Characteristics of Patients With Temporal Lobe Epilepsy

Characteristic	Value
Sex, n (%)	
Female	13 (52)
Male	12 (48)
Age at surgery	
Mean	30.5
Median (range)	28 (7-62)
Age at first seizure	
Mean	19.1
Median (range)	18.8 (0.5-46)
Epilepsy duration	
Mean	11.4
Median (range)	8 (1-40)
Previous medical history, n (%)	
Yes	10 (40)
No	15 (60)
Aura, n (%)	
Yes	14 (56)
No	11 (44)
Seizure frequency, n (%)	
Daily	5 (20)
Weekly	8 (32)
Monthly	12 (48)
MRI, n (%)	
Positive	22 (88)
Negative	3 (12)
Hypometabolism in PET, n (%)	
Unilateral temporal lobe	21 (84)
Bilateral temporal lobe	2 (8)
Unavailable	2 (8)

PET, positron emission tomography.

TABLE 2. Surgical Outcomes of Functional Anterior Temporal Lobectomy

Characteristic	Value
Surgery side, n (%)	
Left	17 (68)
Right	8 (32)
Surgery duration, min	
Mean	174.6
Median (range)	165 (120-270)
Blood loss, mL	
Mean	126
Median (range)	100 (50-300)
Acute postoperative seizures, n (%)	
Yes	1 (4)
No	24 (96)
Complication, n (%)	
Yes	1 (4)
No	24 (96)
Postoperative hospital stay, d	
Mean	8.9
Median (range)	8 (5-15)
Pathology, n (%)	
Hippocampal sclerosis	17 (68)
Gliosis	7 (28)
Cavernous hemangioma	1 (4)
Follow-up, mo	
Mean	8.9
Median (range)	9 (4-14.6)
Seizure outcomes, n (%)	
Engel Ia	23 (92)
Engel II	1 (4)
Engel III	1 (4)
Engel IV	0 (0)

complete disconnection of the pathways of propagation for epileptic activity in patients with TLE. The keynotes of FATL include keyhole surgery with minicraniotomy, amygdalohippocampectomy, and lateral TLD (vs en bloc resection). The extent of disconnecting the lateral temporal lobe is in accordance with ATL.[19] The maximal resection of 6.0 to 6.5 cm of the anterior lateral nondominant temporal lobe or 4.0 to 4.5 cm of the dominant temporal lobe was performed.[19] In our study, the length of lateral disconnection is T1 < T2 < T3, for avoiding a possible postoperative language deficit.

FATL has several remarkable advantages. First, minicraniotomy with a bone flap diameter of 3 cm and an incision length of 6 cm is performed within this procedure, thus contributing to minor trauma. Second, brain shift after the loss of CSF and the removal of mesial structures and temporal stem provides sufficient operating space for facilitating temporal lobotomy, easily guaranteeing the complete disconnection and isolation of the temporal lobe cortex. Third, lateral temporal lobotomy (ie, disconnecting the lateral temporal cortex, in contrast with en bloc resection) avoids potential complications associated with residual cavity after parenchymal defects using ATL. Finally, improved cosmetic appearance of the wound is obtained because of minicraniotomy. Scar wounds, focal hair loss, and muscular atrophy occur commonly in patients undergoing ATL performed using large frontotemporal craniotomy. Thus, FATL is more likely to be accepted by patients as compared with ATL.

Our study suggests that FATL, which presents with the advantage of minimally invasive surgery, is an effective and safe procedure for TLE. A total of 23 patients (92%) were completely seizure-free at the last follow-up. There are several plausible explanations for this high seizure-free rate. First, our patients with FATL were well selected. Specifically, hippocampal sclerosis was the main type of pathological findings in our study. Mesial temporal sclerosis was a positive indicator for seizure remission after epilepsy surgery in a previous meta-analysis.[20] In addition, the follow-up duration was short-term. The seizure-free rate decreased progressively with time. A previous cohort study estimated that the seizure-free probability at 5 years after surgery was 55%.[21] The mortality rate was 0, and the morbidity was low. Permanent morbidity was not found at the last follow-up. Only 1 patient had the complication of hydrocephalus. Fortunately, this complication was cured by ventriculoperitoneal shunt.

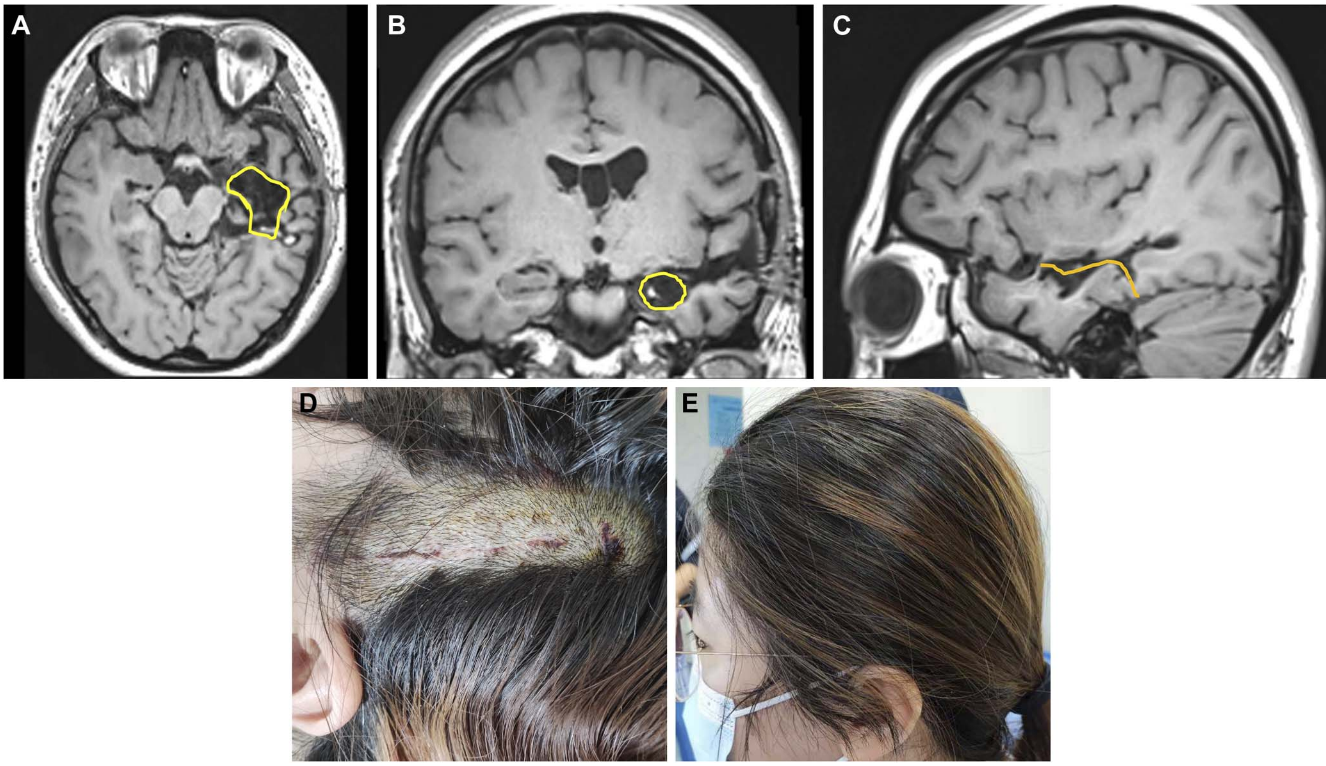

FIGURE 3. *Postoperative MRI of functional anterior temporal lobectomy and the cosmetic appearance of the wound.* **A** *and* **B**, *MRI shows the mesial temporal structures (yellow line) is completely resected.* **C**, *Orange line represents the extent of lateral temporal lobe disconnection.* **D** *and* **E**, *Cosmetic appearance of the wound at 1 week and 3 months after surgery.*

Hydrocephalus is one of the complications of epilepsy surgery. Hydrocephalus presents with a high incidence after hemispherectomy (20% in functional hemispherectomy and 30% in anatomic hemispherectomy).[22] A large retrospective study reported that the incidence of hydrocephalus after epilepsy surgery was 0.7%.[23] The rate of hydrocephalus after surgery for mesial TLE is approximately 0.3%.[24] Enlarged lateral ventricles and cerebral atrophy on presurgical MRI may be a predisposing factor for hydrocephalus. Specifically, bloody CSF after surgery causes an imbalance of CSF circulation for secretion and absorption. Accumulating CSF causes the ventricles to enlarge. Further data will be collected for determining the risk factor of hydrocephalus after FATL.

Limitations

The present study has several limitations. First, the number of enrolled patients undergoing FATL was small. Larger series will be needed to confirm indications, efficacy, and safety for this less-invasive procedure. Second, the follow-up duration in the current study was short. The long-term outcomes of FATL are unknown. Third, comparative studies are necessary to evaluate FATL as an alternative to ATL for the effective management of TLE. Consequently, we should be cautious about the current conclusion. Although these limitations exist, our pilot study has an exciting implication that FATL is a promising therapy for TLE. Certainly, the outcomes of FATL need to be verified in the further study.

CONCLUSION

FATL is a novel, alternative, and viable surgical treatment for TLE. This procedure provides the better efficacy while making the surgery of minimal invasiveness. FATL reduces surgery duration, improves the cosmetic appearance of the wound, and presents with good seizure outcome rates comparable with ATL. Complications of FATL occur uncommonly. A randomized, controlled trial is warranted to provide robust evidence.

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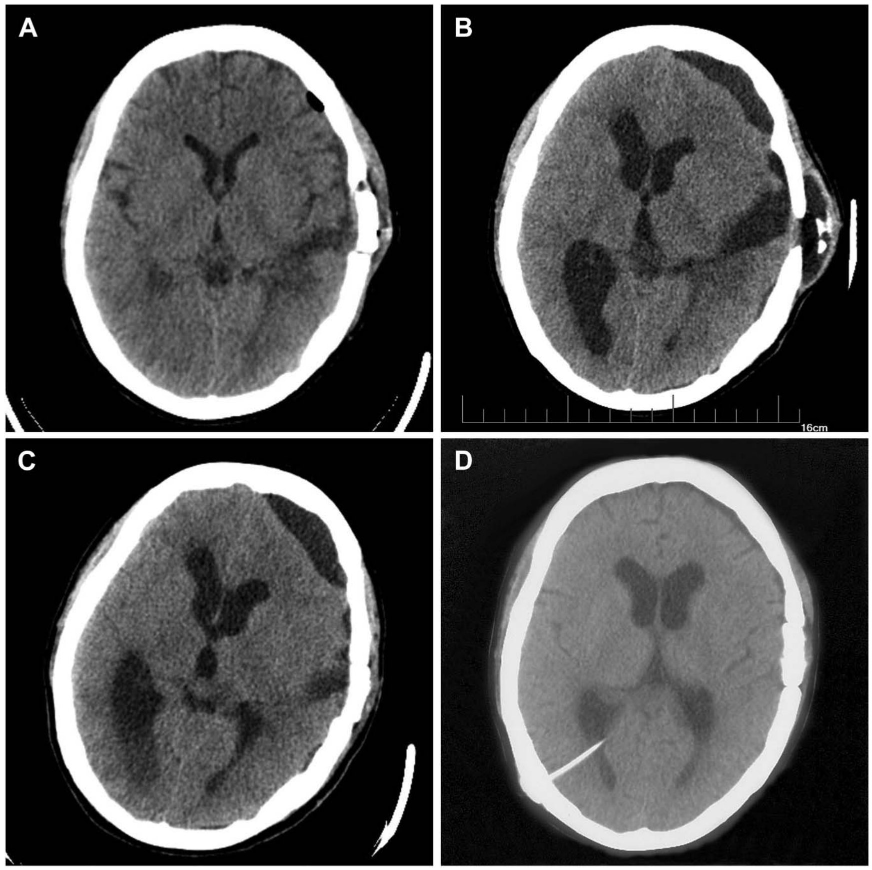

FIGURE 4. *Hydrocephalus after functional anterior temporal lobectomy.* A, *Early performance of brain computed tomographyat 4 days after surgery.* B *and* C, *Hydrocephalus at 1 and 2 months after surgery.* D, *Remission of hydrocephalus at 1 month after shunt.*

Disclosures

The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

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eFigure 1. Brain shifts after anterior temporal lobectomy. **A**, Preoperative MRI. **B**, Brain shifts after surgery.

eFigure 2. Preoperative evaluations of typical temporal lobe epilepsy. **A**, Left hippocampus (red arrow) was atrophic. **B**, Temporal horn of left lateral ventricle was enlarged. **C**, Fluid-attenuated inversion-recovery demonstrated hyperintensity in the left hippocampus (red arrow). **D**, PET. **E**, MRI and PET merging. Metabolism in the left neocortical temporal lobe (black triangle) was more meaningfully decreased than in the right temporal lobe, especially within the left hippocampus (red arrow). **F**, The volumes in the left hippocampus and amygdala were lower than within the right brain. **G**, Sharp waves (black arrow) were recorded as interictal epileptic discharges in the left temporal lobe.

eFigure 3. The Kaplan–Meier curve of seizure freedom after surgery.

VIDEO. Operative video of left functional anterior temporal lobectomy.