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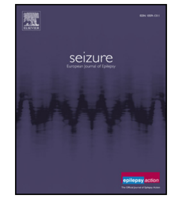

Optimized SEEG-guided radiofrequency thermocoagulation for mesial temporal lobe epilepsy with hippocampal sclerosis

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ABSTRACT

Purpose: Concerns about the impact of open surgery for drug-resistant mesial temporal lobe epilepsy with hippocampal sclerosis (MTLE-HS) have driven interest in minimally invasive techniques. Stereo-electro-encephalography guided radiofrequency thermocoagulation (SEEG guided RF-TC) offers an alternative choice but with currently limited efficacy. We developed a procedure for optimally extended thermocoagulative lesions and investigated the efficacy and safety for MTLE-HS in a preliminary observational study.
Methods: From June 2016 to August 2017, twenty-two patients were selected for the present study. They met the criteria of unilateral MTLE-HS after noninvasive evaluation and then underwent implantation of a combination of SEEG electrodes to form a high-density focal stereo-array, including one electrode along the long axis of amygdalohippocampal complex and three orthogonal electrodes to widely sample mesial temporal structures. A unilateral epileptogenic zone of mesial temporal structures was confirmed in these 21 patients. SEEG-guided bipolar coagulations were performed between two contiguous contacts of the same electrode, or between two adjacent contacts of different electrodes.
Results: Surgical procedures were well tolerated, with no related complications. At the follow-up of 12 months, 20 patients (95.2%) experienced a > 90% decrease in seizure frequency and 16 patients (76.2%) were free of disabling seizures (Engel class I). Among them, eight (38.1%) were classified as Engel class Ia and the other eight (38.1%) as Engel class Ib. Four others (19%) had rare disabling seizures (Engel class II). Only one (4.8%) experienced an Engel class III outcome.
Conclusion: Optimized SEEG-guided RF-TC is a promising complementary option for the treatment of MTLE-HS.

1. Introduction

Mesial temporal lobe epilepsy associated with hippocampal sclerosis (MTLE-HS) remains of special interest due to its high prevalence and frequent drug-resistance [1]. Standard surgical approaches including anterior temporal lobectomy (ATL) or selective amygdalohippocampectomy (SAH) are established effective treatments in medically refractory MTLE-HS patients. Prospective, randomized trials have demonstrated seizure-free rates significantly greater in surgically-treated patients compared to those given best medical therapy [2–4]. Even though the mortality after ATL is minimal, the overall morbidity cannot be ignored. Cognitive impairments, psychiatric disturbances, visual field defects, and cognitive disorders are the most common complications [5].

For patients with MTLE-HS, in recent years, magnetic resonance imaging (MRI)-guided laser interstitial thermal therapy (LiTT) [6–15] has emerged as a promising minimally invasive alternative to classical open resection. But this new surgical technique is not universally available and the indications, safety and efficacy need further evaluation.

Stereo-electro-encephalography (SEEG) has been increasingly adopted for invasive evaluation of intractable epilepsy since the first

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introduction by Talairach and Bancaud in the late 1950s. SEEG electrodes coverage allows a very accurate three-dimensional exploration of the epileptic network, but also provides the chance to generate thermocoagulation lesions of the epileptogenic zone using a radiofrequency (RF) generator connected to the electrode contacts [16]. Comparing with standard open surgery as ATL and SAH, such minimally invasive intervention leads to less patient discomfort, shorter hospitalization, better preservation of cerebral function, and reduced surgical complications. Unlike laser ablation, RF lesioning affords no intraoperative control over lesion temperature and no opportunity for real-time visualization of lesion creation. To date, SEEG-guided RF-TC has been applied in patients with focal lesions such as periventricular nodular heterotopias [17,18] and hypothalamic harmatomas [19].

For patients with temporal lobe epilepsy (TLE), however, SEEG-guided RF-TC performed between two contiguous electrode contacts is not the first-line therapeutic option because of lower and less durable efficacy than ATL [16,20,21]. We speculate that expanding RF-TC lesion size would improve efficacy in MTLE-HS patients. Therefore, we developed a procedure for optimally extended thermo-lesions by applying targeted mesial temporal multi-electrode RF-TC lesions, in order to improve the efficacy in MTLE-HS patients.

2. Methods

2.1. Patients

We conducted an observational case series study for MTLE-HS patients with disabling seizures meeting the International League Against Epilepsy definition of drug-resistant epilepsy [22,23].

From June 1st 2016 to August 31st 2017, forty-one patients were preliminarily considered as having medically refractory MTLE in the Department of Neurosurgery, Xuanwu Hospital, Capital Medical University. Each patient underwent comprehensive noninvasive preoperative evaluation, including semiology analysis, scalp electroencephalography and magnetic resonance imaging (MRI). Some of the patients underwent further investigation based on functional neuroimaging. Patients with distinct lesions such as tumor, cavernous malformation, arteriovenous malformation, infarction, and normal hippocampi, suspected extra-hippocampal or bilateral origination of seizures, dual pathology were excluded.

Thirty-one met the criteria of unilateral MTLE-HS after noninvasive evaluation. Twenty-two patients chose invasive evaluation by SEEG electrodes after discussing ATL, SAH and present study with the research team in detail.

One Patient was excluded from the study since invasive evaluation contradicted the preliminary diagnosis of ‘pure’ unilateral MTLE-HS. Twenty-one patients were finally selected in present study for our optimized SEEG-guided RF-TC (Table 1).

The study was conducted in accordance with the ethical standards of the Declaration of Helsinki. It was approved by the local institutional review board / ethics committee. Informed consents were obtained from all patients. The ethical basis for our approach included the following:

1. Conventional anterior temporal lobectomy (ATL) induces neuropsychological deficits. Although ATL was the primary therapeutic option for patients with TLE in our center, after discussion, some patients preferred the option of more focal lesions.

2. In cases where SEEG might be useful, RF lesions can be done in a single stage, concurrent with SEEG recording, which is not possible with ATL and LiTT.

3. The single-stage procedure with RF lesions minimizes the chance of inaccurate lesion targeting during a second procedure.

4. Complications from electrode placement and thermocoagulation are rare and usually mild [24–27].

5. In cases with poor seizure control outcome after RF lesions, it is possible to perform standard ATL, where appropriate.

6. LiTT therapy is not available at many surgery centers, including ours.

2.2. Implantation of SEEG electrodes

SEEG electrodes had a diameter of 0.8 mm and comprised 5–18 contacts 2 mm in length with 1.5 mm spacing (Alcis, Besancon, France). The contacts can both record intracranial activity when connected to an EEG system and induce lesions when connected to a radiofrequency generator system. Three-dimensional T1-weighted contrast MRI was carried out in order to avoid injury to major vessels. We used a stereotactic robot (ROSA, Montpellier, France) to implant electrodes under general anesthesia.

We implanted electrodes orthogonal to the mid-plane with standard clinical SEEG techniques, in order to evaluate epileptiform activity in mesial temporal structures. We added an electrode along the longitudinal axis of amygdala and hippocampal complex. When clinically indicated, we implanted additional electrodes to search for foci outside the regions covered by standard electrodes. In summary, one electrode (OH) was implanted along the long axis of the amygdalohippocampal complex reaching the amygdala. Three more electrodes were implanted orthogonally through the lateral temporal cortex and targeted the amygdala (electrode TA), the ventral head (electrode TH) and anterior body (electrode TB) of the sclerotic hippocampus along with the adjacent parahippocampal gyrus. The three parallel electrodes (TA, TH, and TB) were designed to be separated from each other by at least 8–10 mm and vertically situated 4–5 mm above or below the longitudinal electrode (OH). To exclude potential extra-hippocampal epileptogenic foci, additional electrodes were implanted in extra-temporal regions individually on clinical grounds in a few patients. Post-operative computed tomography (CT) helped to verify the location of each electrode and to check for hemorrhages or other complications. Reconstruction of subject-specific SEEG electrodes was performed based on co-registration of pre- and post-implantation images and a combination of manual and automatic localization of electrodes (Fig. 1A&B).

2.3. Preliminary in vitro experiment of RF-TC with cross-bonding of contacts

Each contact had one pin in the port of the SEEG electrode (Alcis, Besancon, France). Contact pairs from different electrodes could be connected simultaneously through a dual-port selector linked to the R-2000b RF-TC generator system (Beiqi, Beijing, China), under the bipolar mode setting. This is referred to as cross-bonding, which affords an opportunity for greater current spread and more extensive therapeutic lesions.

The effects of one, two, and three-dimensional RF-TC with cross-bonding of contacts were examined (Fig. 2, *in vitro* test on egg albumen). Contiguous bipolar RF-TC using one electrode was considered one-dimensional. RF-TC using coupled contacts from two electrodes in one plane was two-dimensional. Three-dimensional cross-bonding of various electrode contacts provided a novel method to optimize SEEG-guided RF-TC.

Furthermore, we developed a stable model of RF-TC in polyacrylamide gel (PAG), which allowed us to perform an MRI scan for quantitative analysis. Unpublished data showed that a confluent coagulation field could be created when the contacts’ distances are less than 7 mm. According to the change of ablation size across time, there is a transition point in the curve. This time point typically occurred within 60 s after start of RF-TC. Thus, we adopted 60 s as the duration of RF-TC.

Subsequent *in vivo* observation in two rats (Sprague Dawley) was used to verify that SEEG electrode-guided RF-TC could induce a lesion with a circumscribed boundary.

Table 1
Clinical characteristics, SEEG guided RF-TC related events and outcomes of enrolled 21 patients.

No.	Sex/age (year)	Onset age (year)	Past history	Seizure types	Epilepsy types	Seizure frequency	Number of AEDs	Scalp EEG	MRI	PET	Number of bipolar combination in RF-TC	Events during RF-TC	Outcome at half a year	Outcome at one year
1	F/29	19	–	Focal onset	FIA/motor onset/ FBTC	Monthly	3	L-TL	L-HS	L-TL	32	–	Engel Ia	Engel Ia
2	F/25	12	–	Focal onset	FIA/motor onset/ FBTC	Monthly	2	R-TL	R-HS	UA	29	Prickling-like sharp pain Aura/Focal aware evoked without seizures	Engel Ia	Engel Ia
3	M/37	11	–	Focal onset	FIA	Weekly	4	R-TL	R-HS	R-TL	24	–	Engel Ia	Engel Ia
4	M/20	2	–	Focal onset	FIA	Monthly	3	L-TL	L-HS	L-TL	31	Aura/Focal aware evoked without seizures	Engel Ia	Engel Ib
5	F/27	13	–	Focal onset	FIA	Weekly	2	L-TL	L-HS	L-TL	23	Prickling-like sharp pain	Engel Ia	Engel II
6	M/36	8	–	Focal onset	FIA/motor onset/ FBTC	Monthly	3	R-TL	R-HS	R-TL	32	–	Engel Ia	Engel II
7	F/19	2	–	Focal onset	FIA/motor onset/ FBTC	Monthly	2	L-TL	L-HS	L-TL	31	A habitual seizure evoked	Engel Ia	Engel Ib
8	M/27	16	Febrile seizure	Focal onset	FIA	Monthly	2	R-TL	R-HS	R-TL	32	–	Engel Ia	Engel Ib
9	F/17	8	–	Focal onset	FIA/motor onset/ FBTC	Weekly	2	L-TL	L-HS	L-TL	36	–	Engel Ia	Engel Ib
10	M/18	11	Meningitis	Focal onset	FIA/motor onset/ FBTC	Monthly	2	L-TL	L-HS	L-TL	36	–	Engel Ia	Engel Ib
11	M/32	15	–	Focal onset	FIA	Weekly	3	R-TL	R-HS	R-TL	32	–	Engel Ib	Engel II
12	M/27	15	Febrile seizure	Focal onset	FIA/motor onset/ FBTC	Weekly	3	L-TL	L-HS	L-TL	37	Aura/Focal aware evoked without seizures	Engel Ia	Engel Ia
13	M/26	7	–	Focal onset	FIA	Weekly	3	R-TL	R-HS	R-TL	24	–	Engel Ia	Engel Ia
14	F/21	14	–	Focal onset	FIA	Monthly	1	R-TL	R-HS	R-TL	28	Prickling-like sharp pain	Engel Ia	Engel Ib
15	M/21	1	–	Focal onset	FIA	Monthly	3	R&L-TL	L-HS	L-TL	40	–	Engel Ia	Engel Ia
16	M/23	11	–	Focal onset	FIA	Monthly	3	Negative	L-HS	L-TL	33	Prickling-like sharp pain	Engel Ib	Engel II
17	F/27	15	Febrile seizure	Focal onset	FIA/motor onset/ FBTC	Weekly	3	R&L-TL	R-HS	R-TL	27	Prickling-like sharp pain	Engel Ia	Engel Ib
18	F/23	7	Meningitis/Head trauma	Focal onset	FIA/motor onset/ FBTC	Monthly	2	R&L-TL	L-HS	L-TL	29	Prickling-like sharp pain	Engel Ia	Engel Ia
19	M/35	2	–	Focal onset	FIA/motor onset/ FBTC	Monthly	2	L-TL	L-HS	–	34	–	Engel Ia	Engel Ib
20	F/28	11	–	Focal onset	FIA/motor onset/ FBTC	Monthly	2	R-TL	R-HS	R-TL&FL	33	Prickling-like sharp pain	Engel Ia	Engel Ia
21	M/30	26	–	Focal onset	FIA	Weekly	2	R&L-TL	R-HS	R-TL&FL	32	–	Engel III	Engel III

Abbreviations: AEDs anti-epileptic drugs; F female; M male; L left; R right; TL temporal lobe; FL frontal lobe; HS hippocampal sclerosis; UA unavailable; FIA focal impaired awareness; FBTC focal to bilateral tonic-clonic.

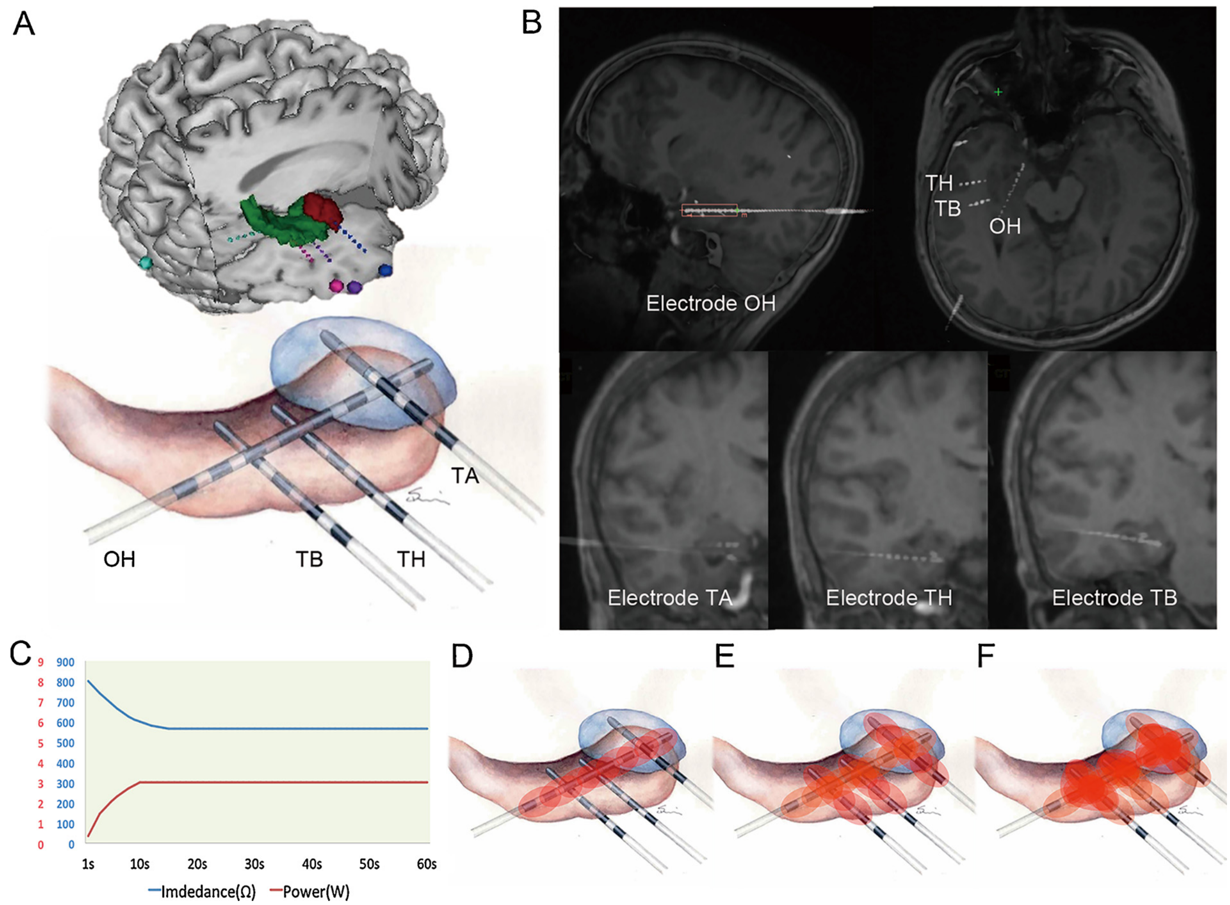

Fig. 1. Optimized SEEG-guided radiofrequency thermocoagulation for MTLE-HS. **A**, Schematic protocol of targeted SEEG-guided three-dimensional cross-bonding RF-TC for MTLE-HS. Electrode OH was implanted along the long axis of the amygdalohippocampal complex, reaching the amygdala. Three more electrodes were inserted orthogonally in the direction of amygdala (electrode TA), and ventral head (electrode TH) and anterior body (electrode TB) of hippocampus. **B**, Post-implantation evaluation of SEEG electrodes targeting the mesial temporal structures by merged images of post-operative CT and pre-operative MRI in a female MTLE-HS patient (No. 2). **C**, RF-TC with a relatively fixed output power (3 W) and longer early ascending period (10 s) resulted in successful thermo-conduction. Proper parameter settings and an optimized power-delivery curve minimized the rate of impedance collapse. **D**, Bipolar coagulation in the ictal onset zone on each two contiguous contacts of electrode OH. **E**, Subsequent bipolar coagulation of the orthogonal electrodes TA, TH, and TB. **F**, Three-dimensional cross-bonding of adjacent contacts in electrodes OH and TA, and TH and TB were further used.

2.4. Optimized SEEG-guided RF-TC in the clinical MTLE-HE series

Patients were video-SEEG monitored for 7–10 days after surgery to capture at least three habitual seizures. Nicolet system EEG data acquisition system with a sampling frequency of 2048 Hz recorded SEEG signals, referencing to a common subcutaneous contact. For each patient, all recorded seizures were visually identified and reviewed. Seizure onset zone (SOZ) was determined by the analysis combined with SEEG recordings and simultaneous seizure semiology during patients' habitual clinical seizures.

A targeted multi-electrode RF-TC procedure was performed to achieve an extensive volume of thermo-lesions based on identification of the SOZ by SEEG. R-2000b generator system delivered power to a maximum level of 3 W within 10 s and maintained this level for the next 50 s. These parameters resulted in successful thermo-conduction (Fig. 1C), generating enlarged confluent 5–7 mm lesions between two connected contacts.

For each patient, we performed bipolar coagulation on each of two contiguous contacts of the longitudinal electrode OH and the orthogonal electrodes TA, TH, and TB within SOZ using same parameters. In particular, three-dimensional cross-bonding of contacts (within SOZ, interval < 5 mm) between electrodes OH and TA, and TH and TB were further used to ablate the tissue (see the video file in Supporting Information, Fig. 1D, E&F). Thus, the modified approach produced an extended thermocoagulation lesion involving the amygdalohippocampal complex, subiculum and part of entorhinal cortex.

SEEG recordings were performed before and 5 min after the RF-TC to observe any change in epileptiform discharges (Fig. 3). The electrodes were then removed, and the patients were discharged one or two days later.

2.5. Follow-up

The patients were followed monthly by telephone, and re-examination at 3, 6 and 12 months. The seizure outcome was evaluated according to the Engel categories [28].

Subjective complaints regarding possible adverse effects were recorded. Routine MRI and scalp EEG were also performed. Similar to the recommendation after open surgery [29,30], we recommended caution in the tapering of antiepileptic drugs after RF-TC, which might also be one of the main effect modifiers.

2.6. Bias control

The potential effect modifiers were considered to include age, sex, duration, and seizure and epilepsy types in this case series study without a control group. The strict inclusive and exclusive criteria were important to minimize the selection bias. The relatively long-time

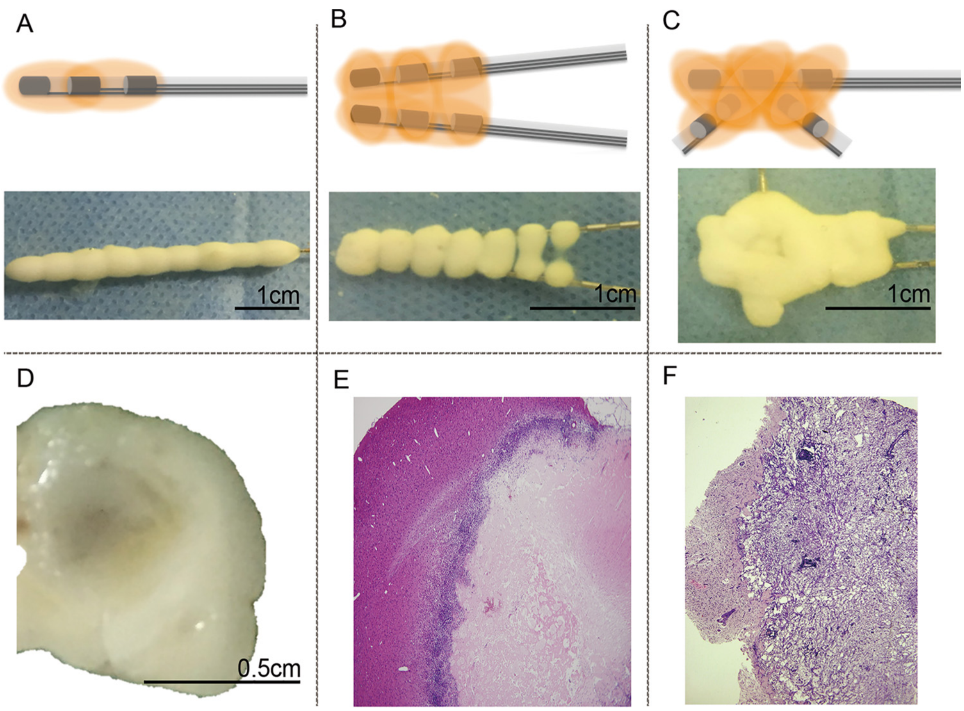

Fig. 2. *In vitro* and *in vivo* results of cross-bonding SEEG electrodes guided. RF-TC.
A, Contiguous dipolar RF-TC using one electrode can be considered one-dimensional. **B**, RF-TC using coupled contacts from two electrodes in one plane is two-dimensional. **C**, Three-dimensional cross-bonding of various electrode contacts is a novel method that can be used to optimize SEEG-guided RF-TC with significantly increased volume and steric configuration of the ablation lesion. The effective distance between electrodes to form confluent lesions in egg white was 4–5 mm. However, the consistency and fluidity of the egg white heavily influenced the RF-TC results. **D**, *In vivo* testing in Sprague-Dawley rats was performed. **E**, HE pathological examination 7 days after RF-TC in rats indicated an obvious interface between the gliocyte proliferation zone with inflammatory cell infiltration and the necrosis zone. **F**, The relative demarcation of the lesion was identified in the human brain.

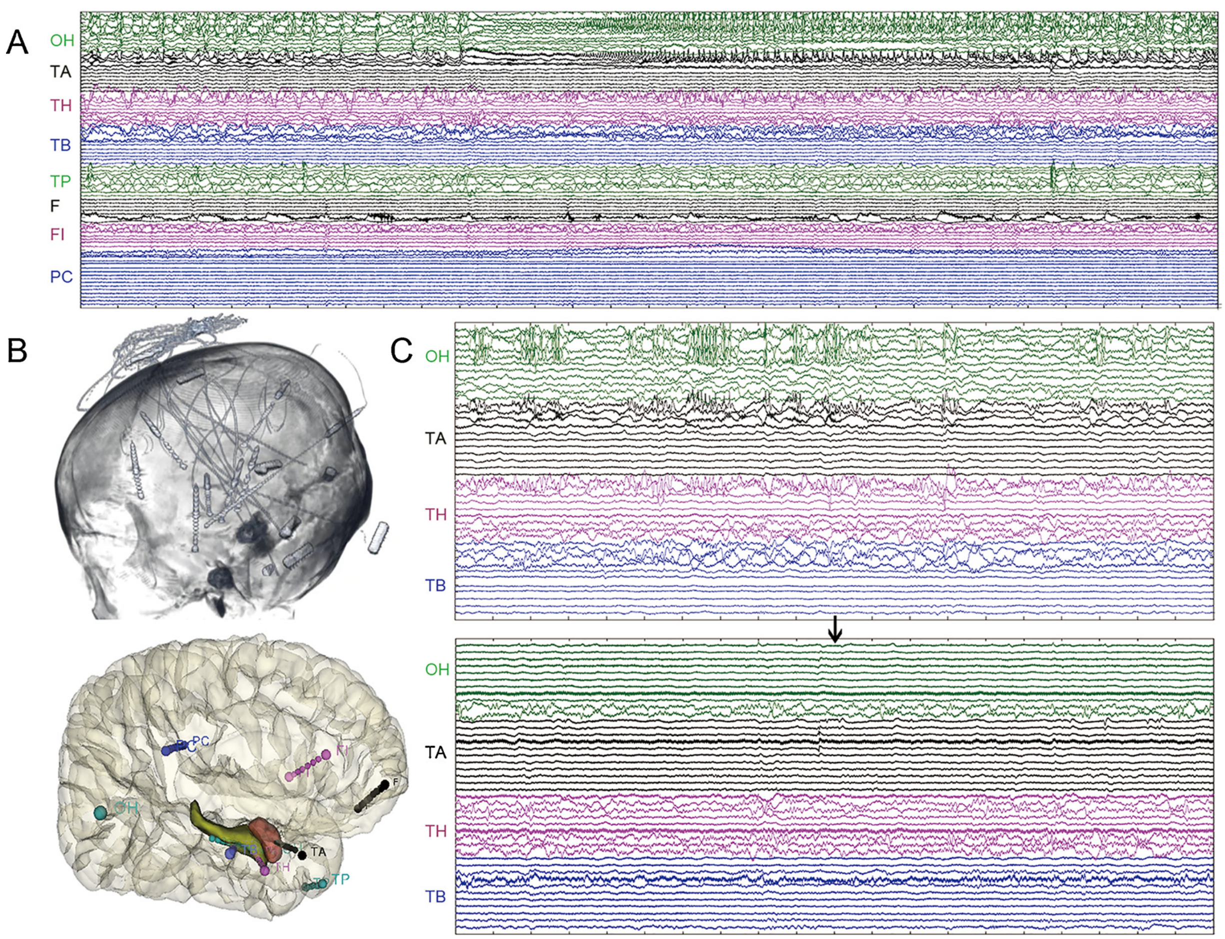

Fig. 3. SEEG before and after RF-TC.
A, In patient No. 2, ictal SEEG monitoring demonstrated seizure origin from the mesial part of the right temporal lobe. **B**, Post-implantation evaluation of SEEG electrodes targeting the mesial temporal structures and the extra-temporal areas by CT (left side view) and cerebral MRI-reconstruction (right side view, FreeSurfer software suite). **C**, Real-time SEEG monitoring indicated that the interictal pathological discharges at the mesial part of right temporal lobe disappeared after RF-TC.

duration of follow-up helped to control the time effect bias. Follow-up by multiple means of communication promoted the response rate and decreased the non-respondent bias. The patient seizure diary and the impartial follow-up questionnaire were useful to control the information bias such as recall bias, inducement bias, and reporting bias.

3. Results

One patient was excluded after SEEG evaluation because of a final diagnosis of lateral-medial TLE. Eventually, 21 patients were confirmed to have 'pure' unilateral MTLE-HS (12 male, 9 female; 26.1 ± 5.8 years old; 11 on the left side and 10 on the right side). Supplementary Fig. 1 in supporting information shows the flow diagram of enrollment and the number of participants at each stage of the study.

The total number of implanted SEEG electrodes was 149 (mean ± SD per patient, 7.1 ± 0.7). Table 1 lists detailed SEEG and RF-TC related events. Transient intracranial prickling-like sharp pain occurred in seven patients (No. 2,5,14,16,17,18,20). Intermittent ipsilateral intracranial hissing or bubbling sounds might occur with sudden collapse of impedance. Aura-like feelings were reported in three (14.3%) patients (No. 2, 4, and 12) on contacts that showed ictal epileptiform discharges. Only one patient (4.8%, No. 7) had a habitual generalized seizure during the thermocoagulation procedure (Table 1).

Postoperative MRI in the 21 patients revealed confluent lesions involving amygdala, anterior portion of hippocampus, subiculum, and part of the entorhinal cortex. These lesions usually were clearly visible within 1 week after thermocoagulation (Fig. 4).

RF-TC procedures were well tolerated by the patients. No neurological defects or other complications were observed during the treatment or the 12-month follow-up, although formal neuropsychological testing was not performed. At the follow-up of 12 months, twenty patients (95.2%) demonstrated a more than 90% decrease of their disabling seizures frequency. According to Engel's classification, 16 out of 21 patients (76.2%) were free of disabling seizures (Engel class I). Of note, residual auras were common, including eight patients (38.1%) classified as Engel class Ia and the other eight (38.1%) as Engel class Ib. Four other patients (19%) had rare disabling seizures with impairments of consciousness (Engel class II). Only one patient (4.8%) experienced an Engel class III outcome, with worthwhile improvement. No patient was classified as Engel class IV (Fig. 5A).

A Kaplan-Meier estimator showed an estimated mean seizure-free survival time of 20.7 months (Std. Error 2.3 months, 95% confidence interval 16.2–25.2 months) for Engel Ia outcome, 20.2 months (Std. Error 1.7 months, 95% confidence interval 16.8–23.6 months) for Engel I, and 18.3 months (Std. Error 1.8 months, 95% confidence interval 14.8–21.9 months) for Engel I-II (Fig. 5B).

4. Discussion

Complications were not encountered in our series, consistent with previous reports [24,25,31]. Working parameters are important for SEEG-guided RF-TC since the electrodes have no feedback of temperature and the lesion is invisible during formation. Optimal parameters, including output power of 3 W achieved over 10 s with a Beiqi R-2000b generator system, helped to reduce sudden collapse of impedance and potential carbonization and adhesion around the contacts. Reduced adhesion might be expected to decrease the risk of hemorrhage when removing the electrodes after RF-TC.

A systematic review and meta-analysis about SEEG-guided RF-TC in patients with drug-resistant focal epilepsy showed that both the seizure-

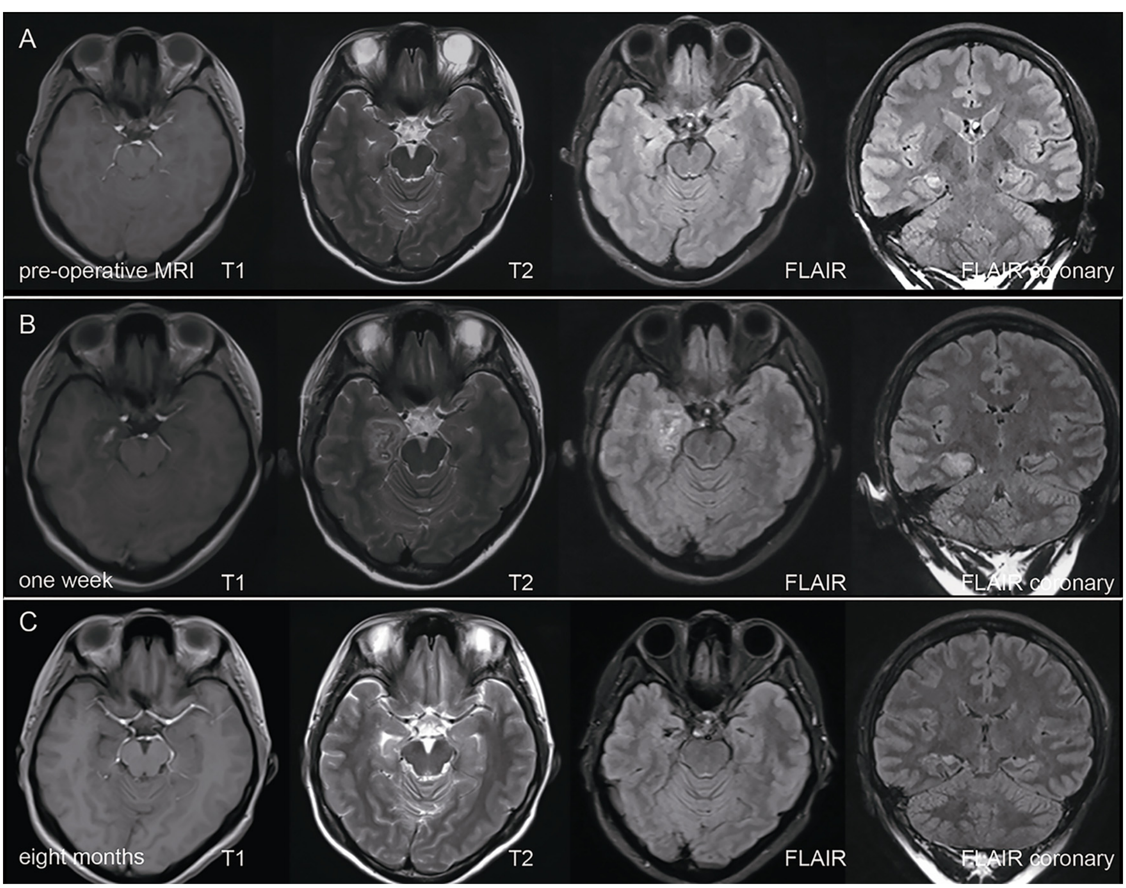

Fig. 4. Pre- and post-operative MRI.
A, Pre-operative MRI showing hippocampal sclerosis on the right side in patient No. 2. **B**, One-week post-surgical MRI showing the thermocoagulative lesion induced by RF-TC. **C**, Atrophy of the mesial temporal structures is visible on the MRI eight months after RF-TC.

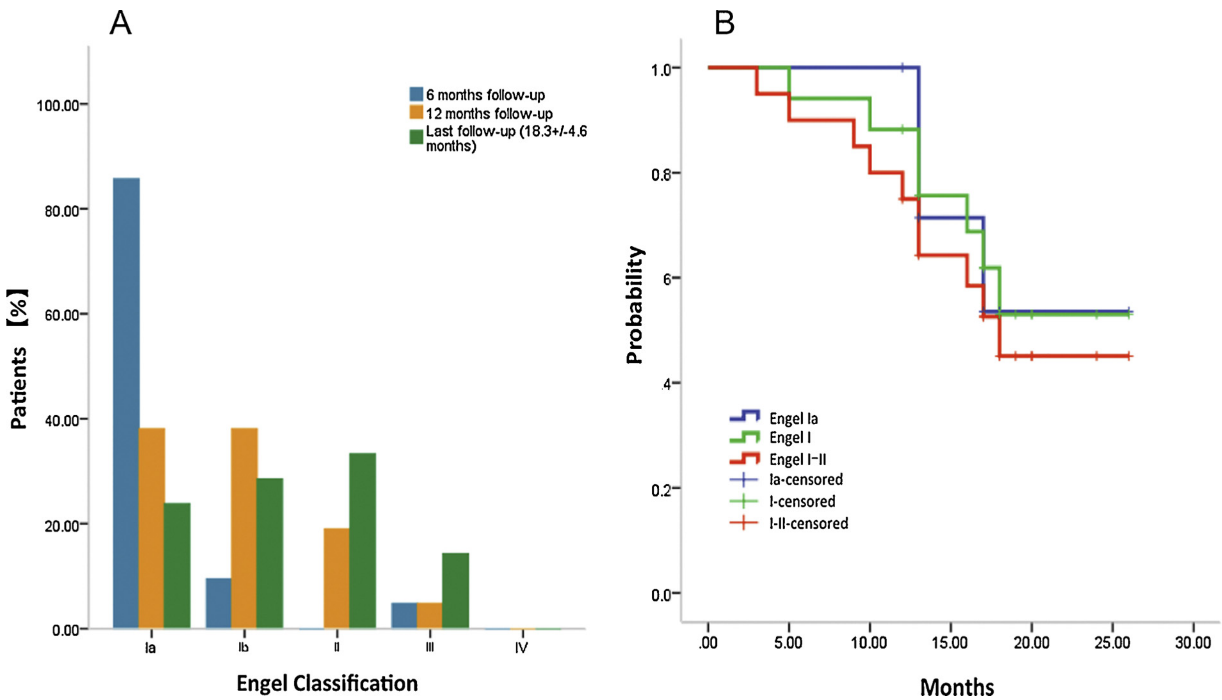

Fig. 5. Seizure outcomes and Kaplan-Meier analysis.
A, Surgical outcomes at 6 months, 12 months, and last follow-up for all 21 patients. **B**, Kaplan-Meier estimates of survival functions for patients with Engel class Ia (blue), Engel class I (green), and Engel class I-II (red) outcomes. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

free and responder rates varied greatly across studies. The level of evidence regarding its efficacy remains low [25]. Specifically, a controlled study in TLE found that SEEG-guided RF-TC was significantly inferior to anterior-temporal lobectomy (ATL) [21]. But, interestingly, a recent study in 9 patients with drug-resistant mesial temporal lobe epilepsy (MTLE) reported that the short-term outcome of seizure control of limited RF-TC with a Radionics electrode was similar to that of surgical resection [32]. The duration of follow-up and study size might contribute to the difference in results.

Our data, however, demonstrated relatively favorable seizure outcomes using a targeted multi-electrode method. The efficacy might be attributed to more extensive ablation of mesial temporal structures. Application of optimized parameters and a novel focal three-dimensional array produced a thermocoagulation lesion, similar in extent to selective amygdalohippocampectomy. Similarly, Staudt et al. have showed larger confluent lesions generated by RF between separate SEEG electrodes [33].

Proper selection of candidates is also critical for ensuring a favorable seizure outcome. Since TLE are heterogeneous in etiology and SOZ location, Kahane et al. divided TLE into five subtypes based on distinct electrophysiology patterns and clinical symptoms with varied treatment strategies [34]. In our study, only MTLE-HS patients were selected because of well-characterized pathophysiology involving distinct mesial temporal lobe substrates. Of note, one patient was excluded due to confirmation of lateral-medial TLE using SEEG.

Surgical resection by ATL in patients with TLE is the most effective treatment for seizure control. In a recent retrospective study of surgical outcomes including 389 patients with MTLE, 83.7% of the patients were classified as Engel Class I after 1–25 years of follow-up [35]. But LiTT has become increasingly used by many centers as an alternative to open surgery in certain patients of drug-resistant epilepsy. The latest Meta-analysis of 16 studies that included 269 patients with drug-resistant epilepsy has showed the safety and efficacy of MRI-guided LiTT in the treatment of drug-resistant MTLE, TLE and insular epilepsy [8].

In comparison to previous clinical trials, our selection criteria were more strict. We are therefore cautious to compare the seizure outcomes of this study and others.

Compared to LiTT [36], SEEG-guided RF-TC has some distinctive characteristics. SEEG accurately locates the epileptogenic zone before ablation. It can eliminate a second procedure and minimize the risk that a second electrode placement might not be at the precise site of recorded epileptiform activity. Furthermore, SEEG-guided RF-TC is relatively more manageable while LiTT has a learning curve of clinical utilization and the related complications and treatment failure have been reported [8,37]. Additionally, SEEG are relatively more widespread while LiTT is not universally available.

SEEG-electrodes guided RF-TC will not likely replace other mesial temporal surgery techniques, but, if the efficacy of our method for producing larger lesions is confirmed, then SEEG-RF-TC will provide another option for selected patients. Limitations of our preliminary study include the small sample size and the uncontrolled design, with no comparator group in a single center. The initial uncontrolled results are encouraging and will require systematic investigation in a larger number of patients. Accordingly, a further randomized control trial has been designed (ClinicalTrials.gov ID NCT03941613) with a brief title "SEEG Guided RF-TC *versus* ATL for mTLE With HS (STARTS)".

5. Conclusion

A modified minimally invasive stereotactic radiofrequency lesion procedure guided by cross-bonded SEEG electrode contacts (to produce larger lesions) might be a promising option for patients with MTLE-HS.

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Disclosure

Robert Fisher consults for Medtronic and owns stock in Cerebral Therapeutics, Inc. None of the other authors have any conflicts of interest to disclose. We confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.seizure.2019.08.011.

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