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Three-dimensional intracranial EEG monitoring in presurgical assessment of MRI-negative frontal lobe epilepsy

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Abstract

Magnetic resonance imaging (MRI)-negative epilepsy is associated with poor clinical outcomes prognosis. The present study was aimed to assess whether intracranial 3D interictal and ictal electroencephalography (EEG) findings, a combination of EEG at a different depth, in addition to clinical, scalp EEG, and positron emission tomography–computed tomography (PETCT) data help to predict outcome in a series of patients with MRI-negative frontal lobe epilepsy (FLE) after surgery.

Patients with MRI-negative FLE who were presurgically evaluated by 3D-intracranial EEG (3D-iEEG) recording were included. Outcome predictors were compared in patients with seizure freedom (group 1) and those with recurrent seizures (group 2) at least 24 months after surgery.

Forty-seven patients (15 female) were included in this study. MRI was found normal in 38 patients, whereas a focal or regional hypometabolism was observed in 33 cases. Twenty-three patients (48.9%) were seizure-free (Engel class I), and 24 patients (51.1%) continued to have seizures (12 were class II, 7 were class III, and 5 were class IV). Detailed analysis of intracranial EEG revealed widespread (>2 cm) (17.4%:75%; $P=0.01$) in contrast to focal seizure onset as well as shorter latency to onset of seizure spread (5.9 ± 7.1 s; 1.4 ± 2.9 s; $P=0.016$) and to ictal involvement of brain structures beyond the frontal lobe (21.8 ± 20.3 s; 4.9 ± 5.1 s; $P=0.025$) in patients without seizure freedom.

The results suggest that presurgical evaluation using 3D-iEEG monitoring lead to a better surgical outcome as seizure free in MRI-negative FLE patients.

Abbreviations: 2GTCS = Secondary generalized tonic–clonic seizure, EEG = Electroencephalography, FCD = Focal cortical dysplasia, FDG–PET = Fluoro-deoxyglucose positron emission tomography, FLAIR = fluid-attenuated inversion recovery, FLE = Frontal lobe epilepsy, MRI = Magnetic Resonance Imaging, PETCT = Positron emission tomography–computed tomography, SEEG = Stereoelectroencephalography, SMA = Supplementary motor area, SOZ = Seizure-onset zone, SPM = Statistical Parametrical.

Keywords: 3D intracranial EEG, epilepsy surgery, focal cortical dysplasia, frontal lobe epilepsy, negative MRI, seizure outcome

1. Introduction

Frontal lobe epilepsy (FLE) accounts approximately up to 30% of partial epilepsies, characterized by recurrent of focal seizures in frontal lobe.[1,2] Although FLE is medically manageable, one-third of FLE patients fail to respond to anti-epileptic medications and continue to have seizures.[3] Surgical treatment has been suggested to be an effective modality for medically refractory FLE. FLE surgery is a common resective procedure performed for focal seizures, accounting for up to 30% of all epilepsy surgeries.[4,5] Nevertheless, it remains challenging due to the heterogeneity of the seizures and the difficulty to comprehensively localize the epileptogenic regions.

Neuroimaging techniques have been suggested to be useful to delineate the lesions responsible for seizures. Among those, magnetic resonance imaging (MRI) has become a standard modality for presurgical evaluation in epilepsy.[6] Due to the nature of MRI, a small portion of epilepsy patients fail to show lesions on an MRI during presurgical assessments, referred to as MRI-negative or nonlesional epilepsy.[7] Despite advance in MRI, absence of lesion on MRI accounts for up to 25% of patients evaluated for respective surgery.[8,9] It has been associated with unfavorable outcome in respective surgical epilepsy.[10] Nevertheless, surgical modality for MRI-negative epilepsy patients relies on invasive intracranial electroencephalography (EEG).[11,12]

Surgical resection for intractable epilepsy with no visible MRI abnormality remains challenging in association with poor surgical outcomes. The present study was aimed to examine usefulness of 3D-intracranial EEG (3D-iEEG) monitoring in the context of pre-surgical evaluation of MRI-negative FLE patients. We focused on clinical usefulness of 3D-iEEG in delineating the epileptogenic zone and postoperative seizure-freedom in FLE patients.

Editor: Bernhard Schaller.

Funding/support: This study was supported by Fujian Provincial Department of Science and Technology (Grant: 2015Y0028).

The authors report no conflicts of interest.

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Medicine (2016) 95:50(e5192)

Received: 10 January 2016 / Received in final form: 20 September 2016 / Accepted: 30 September 2016

http://dx.doi.org/10.1097/MD.0000000000005192

2. Methods

2.1. Patients

The retrospective study was conducted by reviewing medical records of patients with refractory FLE undergoing frontal lobectomy after chronic intracranial EEG recording at Fuzhou General Hospital between January 2007 and December 2012. Exclusion criteria were patients with MRI-detectable lesions undergoing marginectomy directly, patients undergoing surgical resections extending beyond the frontal lobe, or patients with prior brain surgery. A follow-up of at least 2 years was performed. Clinical data were collected and analyzed, including gender, date of surgery, date of seizure recurrence, age at seizure onset and at surgery, side of surgical resection, presence of auras, semiology and frequency of seizure, and results of pre-operative and postoperative EEG and results of pre-operative positron emission tomography (PET). The dominant hemisphere was defined as the hemisphere contralateral to the side of handedness. No patients underwent WADA test. The study was approved by the institutional review board of Fuzhou General Hospital. Written informed consent was obtained from all patients.

2.2. Magnetic resonance imaging

Eligible patients underwent brain MRI using 3.0 T unit (Siemens Magnetom Vision; Siemens, Munich/Erlangen, Germany) with a modified protocol as previously described.[13] In brief, the protocol included following sequences, namely sagittal T-1 weighted, axial/coronal T-2 weighted sequences. The 5 mm thick section with 1 mm image gaps was acquired for whole brain. In addition, T-1 weighted gradient-echo (GRE) sequences and T-2 weighted fluid-attenuated inversion recovery (FLAIR) images were also obtained. These sequences were conducted in all patients.

2.3. 18-Fluoro-deoxyglucose positron emission tomography (FDG–PET)

All patients underwent interictal ^{18}F-FDG-PET for cerebral metabolic rate for glucose utilization measurement using a GE Discovery LS PET/CT scanner (GE Medical Systems, USA) and (Nihon-Kohden Corporation, Japan). Axial raw data were obtained on a PET scanner 60 minutes after the intravenous injection of 18F-fluorodeoxyglucose (FDG; 370 MBq). The acquisition time was approximately 20 minutes. The axial images were reconstructed using a Shepp–Logan filter (cutoff frequency, 5 cycles per pixel) and realigned in the coronal and sagittal planes. Spatial resolution was 6.1 mm × 6.1 mm × 4.3 mm. Visual PET analysis was performed by a trained examiner during the presurgical phase and before 3D-iEEG procedure, using a colored scale allowing detection of metabolic changes, each color corresponding to a 15% variation of FDG uptake. Extent of hypometabolic areas was classified as focal ($\leq$3 cm) or regional (>3 cm). PET and CT were routinely coregistered using ANATOMIST software (SHFJ, CEA, Orsay, France). In addition, individual statistical analysis using SPM5 software (Welcome Department of Cognitive Neurology, London, UK) was secondarily performed.

2.4. Video-EEG monitoring

All patients underwent interictal video-EEG monitoring in accordance with the International 10/20 system of electrode placement. Interictal discharges were recorded to localize the region of onset. All patients were recorded to have at least 3 habitual seizures. EEG ictal patterns were defined to be regional or not by a localized ictal rhythm and confines of electrode implantation in epileptogenic lobe. Clinical seizure semiology was analyzed for lateralization of the seizure-onset zone (SOZ) as previously described.[14]

2.5. Placement of 3D-iEEG (subdural grid, strip, and supplementary depth electrodes)

Placement of 3D-iEEG was performed as previously described.[15] In brief, the locations of the intracranial electrodes (HKHS Beijing Health Co., Ltd, Beijing, China; or AD-Tech Medical Instrument Company, Racine, WI) were determined based on the results of evolving ictal semiology, scalp EEG, and PET-CT. All patients had implantation of subdural grids and strips (contact diameter 2.3 mm, intercontact distance 10 mm). Subjects with severe adhesion were placed with depth electrodes through superior frontal gyrus down to the cingulate gyrus, orbital cortex, and gyrus rectus to prevent brain injury during the course of electrode placement. Tailored to suspected seizure-onset foci categorized as orbitofrontal, frontal convexity, frontopolar, or supplementary motor area (SMA)/medial frontal sublocation, additional intracerebral depth electrodes were placed as well. Two to eight depth electrodes were placed under frameless navigation in each patient. There were three types of electrodes used, which were 6-contact electrode along the length with 10 mm spacing (Type 1), 8-contact electrode along the length with 5 mm spacing (Type 2), and 4-contact along the length with 5 mm spacing (Type 3). Type 1 or 2 electrodes were either inserted orthogonally from the lateral surface to the medial surface or basal surface and Type 3 electrodes were inserted vertically into the suspected lesion or epileptogenic zone. After exposure of the frontal lobe and placement of depth and subdural electrodes, additional smaller grids or strips were slid over the central and postcentral area and lateral temporal neocortex, without direct visualization. Patients with complex partial seizures or a misleading predominant temporal hypometabolism were evaluated for epilepsy origin as previously described.[16]

When lateralization was doubtful, we implanted limited additional subdural strips and/or depth electrodes over the contralateral hemisphere to rule out seizure onset from that side. A 3-dimensional reconstruction map was done to show the location of electrode contacts after implantation. Patients were prescribed with prophylactic antibiotics as long as the electrodes were in place.

2.6. Intracranial EEG analysis

Intracranial EEG of the patients was recorded using a 128 or 192-channel digital video monitoring system (Nihon–Kohden) and analyzed by at least 2 epileptologists. SOZ was defined as a region showing the earliest intracranial EEG change in a seizure including repetitive spikes, background suppression, or paroxysmal fast activity. Ictal-onset zone was classified by location (orbitofrontal, frontal convexity, frontopolar, or SMA/medial frontal sublocation) and distribution (focal, regional, or widespread). Focal onset was defined as involving less than 5 adjacent electrode contacts, whereas regional onset involved more than 5 adjacent contacts. An onset involving more than 20 adjacent electrodes was considered as widespread ictal onset. Ictal onset observed in multifocal or noncontiguous electrodes was classified as widespread distribution. The ictal-onset

discharges were categorized into 3 groups based on frequencies. Primary propagation area was defined as the cortical region involved in the seizure within 3 seconds after EEG onset. Onset of ictal spread was defined as first ictal discharges recorded ≥2 cm from the onset zone. Time lag (seconds) between clinical and electrographic ictal onset was measured. Interictal epileptiform discharges were classified on the basis of the side of resection, mainly (≥80%) at SOZ, beyond (≥10%) SOZ.

2.7. Surgery and extent of resection

All patients underwent lesionectomy, subtotal lobectomy, or frontal lobectomy. The posterior resection margin was determined by the precentral sulcus as defined anatomically and by extraoperative mapping to avoid loss of eloquent cortex. We tried to resect all of the area of ictal onset, persistent pathologic delta slowing, >1 Hz frequent spikes, and the primary propagation area within 3 seconds after ictal onset. We could not perform complete resection in some patients because of multifocal and widespread, or inclusion of eloquent area. Interestingly, some MRI-invisible lesion appeared abnormality in color and texture under microscope, we tried to resect all of the lesions.

2.8. Pathological diagnosis

Tissue sections of cortical resections were immersion-fixed in 10% buffered formalin, embedded in paraffin, and stained with hematoxylin and eosin, Bielschowsky, and cresyl violet stains. A diagnosis of pathological cortical dysplasia was made according to the grading system of Palmini and Lüders.[17]

2.9. Statistical analysis

Data were analyzed by independent 2-sample *t* tests and were presented as mean ± SD. A probability (*P*) value of <0.05 was considered as statistically significant. All statistical analyses were performed with SPSS statistical software (SPSS, Chicago, IL).

3. Results

3.1. Demographic data

A total of 47 patients (32 male, 15 female) were enrolled in this study. Demographic characteristics are presented in Table 1. Of the patients, 38 exhibited normal MRI, whereas the others were found with subtle gyral abnormalities such as unusual gyral depth or sulci patterns and mild blurring of gray and white matter demarcation without any signal change on T2 or FLAIR sequences. Five patients had a history of febrile convulsion, and there was no patient reporting meaningful head trauma and encephalitis. Other clinical characteristics such as age at surgery, seizure frequency, sex, presence of secondary generalized tonic–clonic seizure (2GTCS), presence of possible causes, duration of epilepsy, the frequency of seizures (the number of seizures per month), and side of resective surgery were not related to surgical outcome (Table 1).

Table 1

Demographic data and surgical outcomes.

Patient characteristics	GROUP 1: Seizure-free (23)	GROUP 2: Persistent seizures (24)	*P*
Sex (M:F)	16:7	16:8	ns
Side of surgery (right:left)	8:15	10:14	ns
2GTCS	22	25	ns
Age at surgery, y	26.2 ± 7.7	24.8 ± 8.5	ns
Age at onset, y	12.3 ± 5.8	11.0 ± 9.7	ns
Duration of epilepsy, y	13.9 ± 7.2	13.8 ± 6.6	ns
Frequency of seizures (per month)	7.7 ± 12.3	9.3 ± 29.3	ns

ns = not significant.

3.2. Surgical outcomes

Surgical procedures were performed in all patients of whom 29 underwent left frontal lobe surgery. All patients had a follow-up of at least 2 years after surgery. Of the patients, 23 (48.9%) became seizure-free, 7 (14.9%) had 90% seizure reduction, and the other 12 (25.5%) rarely experienced seizures (Engel Class II), whereas 5 patients (10.6%) exhibited no change after surgery.

3.3. Pathological assessments

Pathology specimens were obtained from 47 patients and examined according to Palmini classification. Pathological assessment revealed that of 41 FCD-positive patients, 15 were with type 1A, 13 were with type 1B, 8 were with type 2A, and 5 were with type 2B. There were 3 cases of focal neuronal loss with gliosis, and 2 cases of ischemic change.

3.4. Objective seizure manifestations

The main objective seizure manifestations were initial versive seizure (13 patients), frontal lobe complex partial seizure (10 patients), initial tonic elevation of arms (10 patients) and initial focal motor seizure (8 patients), followed by complex partial seizure mimicking seizures of temporal lobe epilepsy (3 patients), and sudden secondary 2GTCS (3 patients). Seizure foci were located in orbitofrontal, frontal convexity, frontopolar, or SMA/anterior medial frontal area. No definite and consistent relationship was found between the location of intracranial ictal onset zone and clinical semiology. However, some most active areas were found representative of the ictal onset semiology. The data showed that versive seizures originated from the superior and middle frontal convexity (11/13). The data showed scattered origins of the frontal lobe complex partial seizures throughout the frontal lobe, but with 80% (8/10) in anterior medial frontal area and/or orbitofrontal area. The data showed that complex partial seizure mimicking seizures of temporal lobe epilepsy were initiated from the middle and inferior frontal convexity or orbitofrontal area (3/3). There were 3 patients exhibiting typical SSMA seizures with an ictal onset zone in the SSMA area (the superior or medial frontal areas). In addition, tonic arm elevation as an initial seizure manifestation was found in 5 patients who had intracranial ictal onset zones in association with the posterior superior or middle frontal gyrus, whereas there were 2 patients with the middle frontal lobe.

3.5. EEG predictors of outcome

We next examined the relationship among clinical variables and compared scalp and intracranial EEG features among patients. Interictal EEG showed correctly localizing spikes in 7 of 23 patients who achieved a seizure-free status, whereas 5 of 24 failed. Ictal EEG revealed the lesions in 15 of 23 seizure-free patients, and in 14 of 24 nonseizure-free patients. In contrast, differences in overall presence of ictal discharges and lateralization to the side of resection were insignificant (Table 2).

Table 2

The relationship between concordant lesion or epileptiform abnormalities on each diagnostic modality and surgical outcomes.

Presurgical evaluation	Seizure-free (n = 23)	Persistent seizures (n = 24)
Interictal EEG (localizing*: lateralizing†)	7 : 8	5 : 9
Ictal scalp EEG (localizing*:lateralizing†)	15 : 6	14 : 7
PET (localizing‡: lateralizing§)	18 : 5	5 : 8

EEG = electroencephalography.
* Localization of abnormalities to the frontal lobe.
† Lateralization of epileptiform or slowing abnormalities only without localization.
‡ PET abnormality concordant with localization of resection.
§ PET abnormality concordant with lateralization of resection only without lobal localization.

Intracranial EEG recording revealed that interictal spikes ipsilateral to the side of later resection were observed in both groups. The majority of interictal spikes (defined as 80%) were found in the SOZ. Some interictal epileptiform activity (defined as 10%) beyond the SOZ was noted in 50% of the patients. The results showed that widespread Ictal onset (>2 cm) was observed in both groups associated with ongoing seizures (group 1, 4/23; group 2, 18/24; $P = 0.01$). The 2 groups shared similar distribution of ictal-onset patterns, showing that fast rhythmic activity in the beta to gamma range was found in 65% (15/23) of seizure-free patients compared with 66.7% (16/24) in patients with recurrent seizures. The shorter latency to onset of seizure spread (median; group 1, 5.9 ± 7.1 s; group 2, 1.4 ± 2.9 s; $P = 0.016$) was observed in nonseizure-free patients, as well as to involvement of extrafrontal structures (median; group 1, 21.8 ± 20.3 s; group 2, 4.9 ± 5.1 s; p = 0.025). Moreover, our data showed that patients with recurrent seizures exhibited shorter median latencies between behavioral changes (group1, 15.31 ± 6.1 s; group 2, 14.62 ± 4.4 s) and intracranial-EEG seizure onset (Tables 3 and 4).

Table 3

3D-iEEG electrode information.

Single intracranial EEG monitoring session	47
Several intracranial EEG monitoring sessions	0
Mean number of electrode contacts	118.3 ± 32.7 (74–192)
Mean number of grids	3.66 ± 1.4 (1–5)
Mean number of strips	3.51 ± 1.4 (1–8)
Mean number of depth	5.67 ± 1.4 (2–9)
Bilateral electrode placement	3
Contacts in SOZ	9.5 ± 1.3 (total: 118.3)
Contacts in PP (ictal onset during the first 3 s)	11.3 ± 2.4
Mean number of intracranial seizures recorded	5.2 ± 2.9 (1–87)
Focal onset (n = 47)	16
Regional onset (n = 47)	19
Extensive onset	12
Low amplitude onset (n = 47)	20
Rhythmic onset (n = 47)	22
Both a focal and low amplitude onset (n = 47)	12

EEG = electroencephalography, SOZ = seizure-onset zone.

3.6. Hypometabolism and 3D-IEEG correlations

FDG–PET images were reviewed by 1 experienced nuclear medicine physician blinded to the clinical histories and the results of other presurgical evaluations. The results of the FDG–PET images were categorized into following groups, namely localizing (localized in the epileptogenic lobe) in 23 cases, lateralizing (lateralized in the epileptogenic hemisphere including the epileptogenic lobe) in 13 cases, nonlateralizing (normal or multilobar pattern in both hemispheres) in 11 cases, or false

Table 4

3D-iEEG.

	Group 1 seizure freedom (n = 23)	Group 2 no seizure freedom (n = 24)	*P*
Intracranial EEG characteristics (%)			
Interictal spikes ipsilateral to resection	n = 23 (100%)	n = 24 (100%)	ns
≥80% interictal spikes in SOZ	n = 21/23	n = 18/24	ns
≥10% interictal spikes beyond SOZ	n = 5/23	n = 17/24	ns
Interictal changes, bilateral	n = 1/1	n = 2/2	ns
Ictal onset, widespread	n = 4/23	n = 18/24	0.01
Ictal onset, bilateral	n = 0/1	n = 0/2	ns
Ictal onset pattern, fast rhythmic	n = 15/23	n = 16/24	ns
Ictal onset pattern, gamma	n = 6/23	n = 4/24	ns
Start spread (≥2 cm from onset)	n = 23/23	n = 24/24	ns
Delay start spread	5.9 ± 7.1 s	1.4 ± 2.9 s	0.016
Spread other lobe	n = 11/22	n = 17/24	ns
Delay spread other lobe	21.8 ± 20.3 s	4.9 ± 5.1 s	0.025
Spread contralateral hemisphere	n = 1/1	n = 2/2	ns
Delay spread contralateral hemisphere	17.6 + 13.6	10.6 + 12.6	ns
Correlation clinical ictal onset (arousal/behavioral changes) intracranial-EEG seizure onset			
Sufficient data available	17/23	19/24	ns
Delay	15.31 ± 6.1	14.62 ± 4.4	14.91 (0–92)
Ictal-onset morphology			
Sinusoidal waves (n = 31)	16 (51.6%)	15	ns
Spike or sharp waves (n = 16)	7 (43.8%)	9	ns
Ictal-onset frequency			ns
Beta to gamma (n = 28)	15 (53.6%)	13	ns
Alpha (n = 10)	5 (50%)	5	ns
Delta to theta (n = 9)	3 (33.3%)	6	ns

EEG = electroencephalography, ns = not significant, SOZ = seizure-onset zone.

localizing/false lateralizing (other lobe than the epileptogenic lobe) in no case. No hypermetabolism was found in the dysplastic lesion or epileptogenic zone.

3.7. Complications

There was no operative death. Of all subjects, 4 (8.5%) experienced complications, which were 2 patients with a superficial wound infection treated with oral antibiotics, a patient with pneumonia with intravenous treatment of antibiotics, and the other with a wound infection undergoing removal of the bone flap, debridement, intravenous treatment of antibiotics, and delayed cranioplasty. After SMA resection, 2 of the 3 SMA-localized patients (67%) experienced hemineglect on the contralateral side, which is expected after SMA resection and not considered a complication. All resolved completely and patients were preoperatively informed about this risk.

4. Discussion

Surgical resection of an epileptogenic lesion within an ictal onset zone has been associated with favorable clinical outcome.[18,19] Identification of a specific lesion in epileptic area plays a critical role in achieving satisfactory surgical outcome.[20] In the present study, we reported that the 3D-iEEG recording led to an improved postoperative seizure-freedom in MRI-negative FLE patients who were denied epilepsy surgery. We found that a focal hypometabolism on FDG-PET and a concordant presence of a localized or regional ictal onset on 3D-iEEG were significantly positive prognostic factors. Our results revealed that extensive epileptogenic zone with impossible complete resection, widespread epileptogenicity as indicated by rapid onset of spread of ictal activity likely were associated with poor seizure control after frontal resective surgery.

The role of MRI in diagnosis of epilepsy is well accepted.[21] MRI protocol for presurgical evaluation of patients with refractory epilepsy is being increasingly recognized. Due to the noninvasive nature of MRI, it has become one of mostly used modality for managing lesional epilepsy.[22] It is agreed that MRI in patients with intractable seizure and no lesion is of limited value. Despite advance in MRI, best-practice MRI sequences, and new high-field MRI (3 Tesla) have been reported to fail Taylor's focal cortical dysplasia (TTFCD) cases,[23–25] especially for small lesions deeply located in the medial aspect of the brain or at the bottom of the sulcus. Respective surgeries in FLE patients, especially those with normal MRI findings, remain challenging due to requirements of intensive intracranial EEG studies leading to great surgical risks. In this study, our results showed that use of 3D-iEEG for presurgical evaluation in MRI-negative FLE patients led to a seizure-free rate of 50%. It is suggested that resective surgery can be offered to MRI-negative patients presurgically assessed by 3D-iEEG. Nevertheless, due to invasive nature of EEG, patients undergoing 3D-iEEG are exposed to a degree of risk to infection.

Stereoelectroencephalography (SEEG) is suggested to be useful for presurgical assessment by recording discharges in deep structures and buried cortex, which are not detectable by subdural or cortical electrodes.[26–28] SEEG has been employed to examine the relations between seizure onset regions and propagation.[29] However, SEEG fails to achieve a mapping for the broad frontal lobe and central areas.[30,31] In the present study, 3D-iEEG was developed and introduced, which includes subdural electrodes all over the 3 surfaces and supplementary depth electrodes in the brain. Given the placement of electrodes, 3D-iEEG is suggested to be effective for the comprehensive frontal lobe sampling and mapping. Moreover, 3D-iEEG represents a useful modality providing complementary information to surgical resection upon planning.

Detailed analysis of 3D-iEEG recordings revealed that rapid onset of seizure spread is an independent predictor for ongoing seizures after frontal lobe surgery. It is suggested that an epileptogenic area extends beyond the actual SOZ. The findings indicate that incomplete resection of this tissue may contribute to a great probability of relapse. In addition, rapid spread is known to be a feature of defective inhibitory network and distributed pathology in cortex, suggesting a role of frontal lobe neuronal connections in spread of seizure activity.[32] Our data were consistent with the findings of previous study showing that brain resection led to a great chance of a seizure freedom.[33]

In this study, we found that characteristic interictal surface and depth EEG abnormalities were often present in focal dysplasia cases. Furthermore, intralesional interictal activity and ictal discharges recorded by depth electrodes during 3D-iEEG monitoring were read as characteristics of the dysplastic tissue. However, such activity has been suggested to possibly be recorded in only 1 or 2 contacts of a single intracranial electrode. Neuroimaging techniques such as FDG-PET is necessary for FCD localization.[34] Sensitivity of PET has been low in extratemporal cryptogenic epilepsies. In the present study, we observed a better sensitivity of 18FDG-PET than previous reports. A possible explanation is an increased intrinsic resolution of the PET camera. Previous study has shown that using colored scale and PET/CT coregistration enhanced detection of mild FCDs.[35] In MRI-negative epilepsy cases, overlapping PET images on MRI has resulted in an increased sensitivity, allowing detection of 84% of FCDs.[36] In agreement with previous study, we found that hypermetabolism was absent in FCDs patients during PET even though continuous interictal spiking generated by the dysplastic cortex is known to increase the metabolic demand. It has been postulated that abnormal giant cells that characterize TTFCD fail to capture FDG during the interictal phase. A combination of visual PET/CT coregistration and SPM procedure is recommended to improve the sensitivity of PET.[37]

The present study has several limitations, including retrospective methodology, a small number of cases, and a lack of comparison of locations and extent resection between cases. The present cohort study was expected to contribute to overall decision making regarding FLE surgery. Future prospective case–control studies will provide further information and evidence supporting the applicability of the monitoring techniques.

In conclusion, MRI-negative FLE are amendable after presurgically evaluated by 3D-iEEG. FLE patients assessed with 3D-iEEG before resection have relatively favorable surgical outcome as well as seizure-free rate.

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