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The surgical outcome of patients with bilateral temporal lobe epilepsy

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ABSTRACT

Objectives: The purpose of this study is to explore the surgical outcome of unilateral anterior temporal lobectomy (ATL) for patients with bilateral temporal lobe epilepsy (BTLE).

Methods: We retrospectively reviewed the data of patients who were diagnosed with BTLE by scalp electroencephalogram (EEG) and underwent ATL from 2001 to 2015. In addition, 80 patients were randomly selected as a control group.

Results: One hundred seventeen patients were included in this study and were divided into four groups by intracranial recordings as follows: 78 patients with unilateral seizure onset (Group 1), 13 patients with lateralizable dominant seizure onset (Group 2), 14 patients with lateralizable neuroimaging abnormalities (Group 3), and 12 patients without lateralizable dominant seizure onset or neuroimaging abnormalities (Group 4). The 12 patients in Group 4 declined surgical resection, whereas the remaining 105 patients received ATL, and 93 of them were followed up for more than 1 year after surgery. At the 1-, 2-, and 3-year follow-ups the percentage of patients who were seizure free was 52.9%, 56.5%, and 58.9%, respectively. For the mean postoperative efficacy, there was a statistical difference in patients who were seizure free either between Group 1 + Group 2 + Group 3 and the control group (44.1% vs. 67.5%, $p = 0.002$), or between Group 1 and the control group (48.5% vs. 67.5%, $p = 0.019$), or between Group 2 + Group 3 and the control group (32.0% vs. 67.5%, $p = 0.002$). However, the difference was significant only at the first year follow-up, and there was no significant difference afterward.

Significance: Although the surgical outcome of patients with BTLE is not as good as that of patients with unilateral TLE in short-term follow-up, quite a portion of these patients could benefit from unilateral temporal lobe resection in the long term.

1. Introduction

Patients with temporal lobe epilepsy (TLE) are thought to be good candidates for epilepsy surgery. However, the proportion of patients who are seizure free following anterior temporal lobectomy (ATL) remains suboptimal, with a seizure-free rate at short-term follow-up between 66% and 70% (McIntosh et al., 2001; Spencer and Huh, 2008; Tellez-Zenteno et al., 2005; West et al., 2015). Patients with bilateral temporal lobe epilepsy (BTLE) are thought to be one of the reasons for the low rate of seizure freedom (Andrade-Machado and Benjumea-Cuartas, 2016; Barba et al., 2016). Although the traits and treatments of BTLE were discussed in some previous reports (Boling et al., 2009; Chkhenkeli et al., 2013; Ding et al., 2016; Kuba et al., 2003), the strategy of diagnosis and treatment of BTLE is still controversial. Some reports showed relatively good results of epilepsy surgery for patients with BTLE (Aghakhani et al., 2014; Boling et al., 2009; Di Vito et al., 2016; Hirsch et al., 1991a; Sirven et al., 1997), but it is still commonly considered that surgical treatment should not be considered in patients with BTLE (Didato et al., 2015). Actually, the diagnostic criteria and surgical procedure in different reports were not the same. Therefore, more surgical data are needed to evaluate the surgical outcome under the same criteria and procedure.

In this article, we present the data of patients with BTLE according to the same criteria and who received the same process of surgical evaluation at a single epilepsy center. BTLE was diagnosed when the patient showed at least one of the following features according to long-term video electroencephalogram (EEG) monitoring: 1) the ictal EEG simultaneously involved the two temporal lobes, without the possibility of lateralizing its onset in at least one seizure; 2) the lateralizable features of semiology were inconsistent to the ictal EEG; and 3) the ictal

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EEG alternately arose from the two temporal lobes in at least two different seizures. Referring to Didato's definition (Didato et al., 2015), seizures with the traits of 1 and/or 2 were classified as non-lateralizable bitemporal seizure, and seizures with the trait of 3 were classified as independent bitemporal seizure. We discuss the treatment strategy and surgical outcome of BTLE according to these criteria.

2. Methods

2.1. Patient selection

We retrospectively reviewed the clinical data of patients who underwent surgical treatment for medically intractable epilepsy at the Comprehensive Epilepsy Center of Beijing between October 2001 and October 2015. Patients who met all these conditions were included: 1) Patients who were diagnosed with BTLE according with our criteria; 2) patients who received bilateral intracranial electrode implantation to lateralize the epileptogenic zone (EZ); and 3) patients who were identified as having TLE according to the intracranial recording.

In addition, a comparable number of patients during the same period were randomly selected as a control group. In these patients, the EZ could be localized by non-invasive investigation, and unilateral ATL was performed in these patients.

2.2. Presurgical evaluation

2.2.1. Magnetic resonance imaging

All the patients underwent a high-resolution magnetic resonance imaging (MRI) protocol that was performed using a 1.5 T or 3.0 T MR Scanner (Siemens, Munich/Erlangen/Verio, Germany) and consisted of conventional spin-echo T1-weighted axial, sagittal, coronal, and T2-weighted axial sequences (section thickness of 5 mm, image gaps of 1 mm). In addition, fluid attenuated inversion recovery (FLAIR) images were obtained with a thickness of 5 mm. The transversal and coronal sections were respectively acquired in parallel with or perpendicular to the long axis of the hippocampal formation. Three-dimensional (3D) anatomical T1-weighted axial, sagittal, and coronal sequences covering the whole brain volume with a 1-mm section thickness also were performed to observe the cortical structure.

2.2.2. Scalp video-EEG monitoring

Long-term scalp video-EEG monitoring was performed for each patient (Micromed, Treviso, Italy). The scalp electrodes were arranged according to the international 10–20 electrode system, and as a rule, sphenoidal electrodes were inserted. The duration of scalp video-EEG monitoring ranged from 3 to 14 days, and at least more than three habitual seizures were recorded to determine the seizure onset zone. The anti-epileptic drugs (AEDs) were usually reduced gradually to facilitate the recording of seizure. The seizure onset and the propagation characteristics were analyzed independently by two EEG experts who were aware of the clinical and neuroimaging data [e.g., MRI, positron emission tomography-computed tomography (PET-CT), and magnetoencephalogram].

2.2.3. Principle of intracranial electrode placement

For the patients who were diagnosed with BTLE according to long-term video-EEG monitoring, bilateral subdural or depth electrodes were implanted according to the information acquired from non-invasive presurgical evaluations. Usually, the bilateral depth electrodes were placed stereotactically into hippocampal structures by a posterior lateral approach. The subdural strip electrodes were placed through burr holes to cover the temporal cortex, especially the basal temporal cortex, or the cortex surrounding the sylvian fissure, and even the frontal cortex. All the patients in control group did not undergo invasive EEG recording.

2.2.4. Intracranial EEG monitoring

Intracranial EEG (iEEG) monitoring was performed to further lateralize and localize the EZ. The iEEG sampling rate was set at 1024 Hz for recording more details of seizure propagation. At least more than three habitual seizures were recorded for each patient. The majority of seizure onset zones were identified visually on iEEG traces during the long-term iEEG monitoring. According to the seizure onset recorded by iEEG, the patients were further classified as patients with lateralizable bitemporal seizures and independent bitemporal seizures.

2.3. Classification and surgery

The surgical resections were planned according to the result of iEEG and other non-invasive results. Classical ATL was performed for patients (less than 4.5 cm in length in left temporal lobe and less than 5.5 cm in length in right temporal lobe, including mesial temporal structure and hippocampus). Additionally, intra-operative ECoG before and after the resection was performed. Supplementary tailored resections were performed for some patients with obvious residual epileptic activities in posterior temporal cortex.

The patients were classified into four groups. Group 1: the patients who demonstrated unilateral temporal seizure onset by iEEG and underwent ATL. Group 2: the patients whose iEEG demonstrated bilateral seizure onsets with dominant laterality (So et al., 1989) ($>$ 80% of the seizures recorded from one temporal lobe) and underwent ATL of the dominant side. Group 3: the patients who demonstrated seizures originating from each temporal lobe independently without significant lateralized predominance, whereas unilateral specific neuroimaging abnormalities were found in one temporal lobe. These patients also received ATL in accordance with the abnormal MRI findings. Group 4: the remaining patients whose iEEG showed independent bilateral seizure onset and without seizure laterality or lateralizable MRI abnormalities. Instead of resective surgery, some of these patients received vagus nerve stimulation (VNS) or deep brain stimulation (DBS), and some patients elected to postpone the surgery and continue pharmacological treatment.

2.4. Follow-up and outcomes

After ATL, patients were followed up for at least 12 months to observe surgical outcomes. The postoperative AEDs were usually remained unchanged after operation if the AEDs were appropriate before operation. Occasionally, we postoperatively reduced the number of AEDs to two with seasonable dose for some patients who had more than two kinds of AEDs. Follow-up information was based on outpatient and hospital visits, questionnaires during visits, and telephone interviews. Long-term outcome classification (OC) proposed by the ILAE Commission Report was performed to report the patients' postoperative outcome (Wieser et al., 2001). The definition of each OC was as follows: OC1 means patient achieved complete freedom from seizure and without auras; OC2 means only auras and no other seizures; OC3 means patient had one to three seizure days per year that included auras. Patients with an outcome of OC1 to OC3 were seen as patients with good outcome.

2.5. Statistical analysis

Analysis of variance and Fisher's exact probability test were used to compare the age of seizure onset/surgery, disease duration, the mean postoperative follow-up, and gender composition among four groups. Mann-Whitney tests were used to compare the age at the time of onset, the age at the time of surgery, disease duration, and the mean time of follow-up between two groups. Kaplan-Meier survival analysis was applied to calculate the probability of seizure freedom in the overall group over time. All statistical data analyses were conducted using SPSS software (version 17.0, SPSS, Inc., Chicago, Ill., USA). A p-value < 0.05 was considered significant.

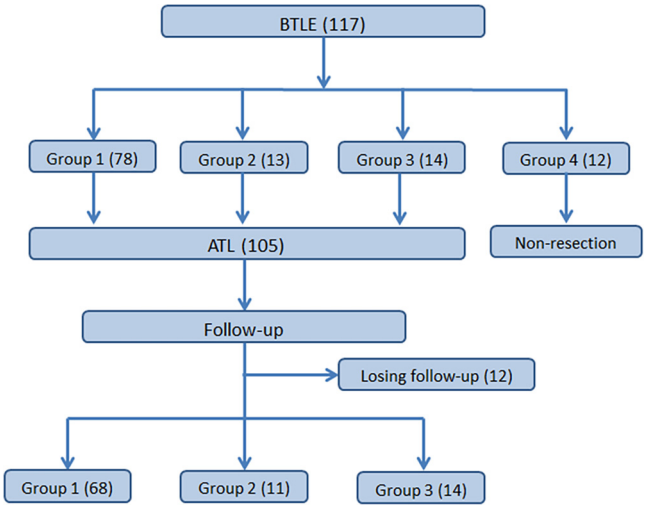

Fig. 1. Flowchart of the screening process of suspected BTLE. Group 1: Patients with unilateral seizure onset; Group 2: Patients with lateralizable dominant seizure onset; Group 3: Patients with lateralizable neuroimaging abnormalities; Group 4: patients without lateralizable dominant seizure onsset or neuroimaging abnormalities.

3. Results

3.1. Patients and classification

Among the 2233 patients we initially reviewed, 117 patients were included in this study according to our criteria. In the 117 patients, 78 (78/117, 66.7%) patients were eventually classified as having lateralizable bitemporal seizures, which was confirmed by intracranial recording (Group 1). Whereas, 39 (39/117, 33.3%) patients were confirmed as patients with independent bitemporal seizures. Among these 39 patients, 13 (13/39, 33.3%) patients showed predominance (> 80%) of seizure onset in one temporal lobe (Group 2), 14 (14/39, 35.9%) patients had approximate proportion of seizure onsets with a lateralizable neuroimaging abnormality in the temporal lobe (Group 3), and the remaining 12 (12/39, 30.8%) patients had approximate independent bilateral seizure onsets without asymmetric MRI (Group 4). The complete screening process is shown in Fig. 1.

3.2. Surgical treatment

In total, 89.7% (105/117) of patients with BTLE received ATL, including 78 patients with lateralizable bitemporal seizures (Group 1) and 27 patients with independent bitemporal seizures (Group 2 + Group 3). Twelve patients with independent bitemporal seizures elected to forgo surgical resection (Group 4).

3.3. Demographic data

In total, 93 of 105 (88.6%) patients who underwent ATL were followed up for more than 1 year after surgery. The general clinical characteristics are shown in Table 1. The gender, the age at onset of seizure, the age at surgery, and disease duration had no significant difference among the four groups. Furthermore, there was no statistical difference of the follow-up duration among Group 1, Group 2, Group 3, and the control group. In the 93 suspicious BTLE patients, 67.7% of patients had lesional MRI, whereas 32.3% of patients had non-lesional MRI findings. In control group, 85% of patients had lesional MRI results and 15% of patients had non-lesional MRI. The histopathology findings were classified into four groups: malformation of cortical development, neoplasm, hippocampal sclerosis and dual pathology. The proportion of patients with different pathological pattern in each group was shown in Table 1.

3.4. Postoperative follow-up

The detailed seizure control outcomes are listed in Table 2. For the mean postoperative efficacy, there was a statistical difference in OC1

Table 1
Demographic data of the patients.

Parameter	G1 + G2 + G3	G1	G2	G3	G4	Control Group
	93	68 (64.8)	11 (10.5)	14 (13.3)	12 (11.4)	80
Male gender	51 (54.8)	39 (57.4)	6 (54.5)	6 (42.9)	7 (58.3)	42 (52.5)
Age at onset						
Mean ± SD	13.6 ± 7.4	13.7 ± 7.8	16.2 ± 6.4	11.1 ± 6.2	17.7 ± 8.2	13.9 ± 9.9
Range	0–27	0–27	3–24	3–22	2–31	0–42
Age at surgery						
Mean ± SD	27.3 ± 8.3	27.4 ± 8.4	29.7 ± 10.3	24.9 ± 5.7	29 ± 9.9	25.5 ± 8.9
Range	12–49	12–46	16–49	14–35	14–48	6–52
Epilepsy duration						
Mean ± SD	13.7 ± 7.3	13.8 ± 7.2	13.6 ± 8.1	13.8 ± 7.3	11.3 ± 5.4	11.7 ± 6.2
Range	2–33	2–33	2–26	3–27	3–21	1–24
MRI						
Lesional	63 (67.7)	43 (63.2)	6 (54.5)	14 (100)	7 (58.3)	68 (85)
Non-lesional	30 (32.3)	25 (36.6)	5 (45.5)	0	5 (41.7)	12 (15)
Ictal EEG						
Nonlaterable	62 (66.7)	49 (72.1)	5 (45.4)	8 (57.2)	3 (25)	–
Independent	6 (6.4)	2 (2.9)	3 (27.3)	1 (7.1)	5 (41.7)	–
Inconsistent with MRI	25 (26.9)	17 (25)	3 (27.3)	5 (25.7)	4 (33.3)	–
Histopathology						
HS	12 (12.9)	10 (14.7)	0	2 (14.3)	–	30 (37.5)
MCD	48 (51.6)	35 (51.5)	8 (72.7)	5 (35.7)	–	26 (32.5)
Neoplasm	7 (7.5)	4 (5.9)	0	3 (21.4)	–	17 (21.2)
Dualpathology	26 (28)	19 (27.9)	3 (27.3)	4 (28.6)	–	7 (8.8)
Mean follow-up (y)						
Mean ± SD	4.4 ± 3.2	4.7 ± 3.4	3.6 ± 2.6	3.2 ± 2.0	–	4.3 ± 2.9
Range	1–15	1–15	1–7	1–7	–	1–15

G-Group, SD-standard deviation, HS- hippocampal sclerosis, MCD-malformation of cortical development (including focal cortical dysplasia, heterotopia, etc).

Table 2
The comparision of outcome among different groups.

Index		G1 + 2 + 3	G1	G2	G3	G2 + 3	Control G	P value				
								Among three G	G1 vs.G2 + 3	G1 + 2 + 3 vs. Control	G1 vs. Control	G2 + 3 vs. Control
total	OC1	44.1%	48.5%	27.3%	35.7%	32%	67.5%	0.332	0.155	0.002**	0.019*	0.002**
1 year	OC1	52.9%	52.9%	36.4%	35.7%	36%	71.3%	0.35	0.147	0.003**	0.022*	0.001**
	OC1 + 2 + 3	73.1%	73.5%	81.8%	64.3%	72%	83.8%	0.611	0.883	0.101	0.128	0.192
2 years	OC1	56.5%	58.5%	50%	40%	43.8%	66.7%	0.54	0.299	0.279	0.369	0.094
	OC1 + 2 + 3	69.6%	67.9%	66.7%	50%	56.3%	73.3%	0.549	0.39	0.699	0.528	0.186
3 years	OC1	58.9%	60.5%	50%	57.1%	53.9%	66.7%	0.883	0.671	0.514	0.569	0.411
	OC1 + 2 + 3	69.6%	72.1%	66.7%	57.1%	61.5%	69.4%	0.717	0.468	0.984	0.796	0.602
P (among 3 years)	OC1	0.388	0.702	0.805	0.637	0.569	0.808	–	–	–	–	–
	OC1 + 2 + 3	0.852	0.789	0.711	0.782	0.565	0.157	–	–	–	–	–

Superscript * stands for $p < 0.05$, Superscript** stands for $p < 0.01$, OC-outcome, G-Group.

either between Group 1 + Group 2 + Group 3 and the control group (44.1% vs. 67.5%, p = 0.002), or between Group 1 and the control group (48.5% vs. 67.5%, p = 0.019), or between Group 2 + Group 3 and the control group (32.0% vs. 67.5%, p = 0.002). For the total patients in Group 1 + Group 2 + Group 3, the seizure-free portion was 52.9%, 56.5%, and 58.9%, respectively, at the first year, second year, and third year follow-up. The portion of patients reaching OC1 + OC2 + OC3 was 73.1%, 69.6%, and 69.6%, respectively, at the first year, second year, and third year follow-up. There was no statistical difference among the 3 years followed. In addition, no significant difference in OC1 and OC1 + OC2 + OC3 was observed among the three groups. There was no significant difference between the outcome of Group 1 and Group 2 + Group 3. A higher percentage of patients were seizure free (OC1) in the control group than that in Group 1 + Group 2 + Group 3 at three follow-up visits, whereas the difference was significant only at the first year after surgery (52.9% vs. 71.3%, p = 0.002). Similarly, the difference between Group 1 and the control group (52.9% vs. 71.3%, p = 0.022), or between Group 2 + Group 3 and the control group (36% vs. 71.3%, p = 0.001) was significant only at the first year follow-up. The outcome of seizure control in the three groups and the control group is shown in Fig. 2.

Additionally, comparison of outcome among different groups based on MRI finding was listed in Table 3. According to MRI findings, the outcome between lesional group and non-lesional group was not significantly different in any group. Among which, the 3-year's outcomes of patients with lesional finding and non-lesional finding in Group 1 + 2 + 3 were obviously different (p = 0.067).

3.5. Results of Kaplan-Meier analysis

The long-term risk of seizure relapse following ATL, and the Kaplan-Meier analysis of time to seizure recurrence for all patients, is shown in the left portion of Fig. 3. The probability of being seizure free 1 year after surgery was 51.4% [95% confidence interval (CI): 41–61], and 50.4% at 2 years (95%CI: 41–60). The results of Kaplan-Meier analysis for the three groups respectively is shown in the right portion of Fig. 3. The probability of being seizure free at 1 year after surgery was 55.1% (95%CI: 44–66) for Group 1, 36.9% (95%CI:10–64) for Group 2, and

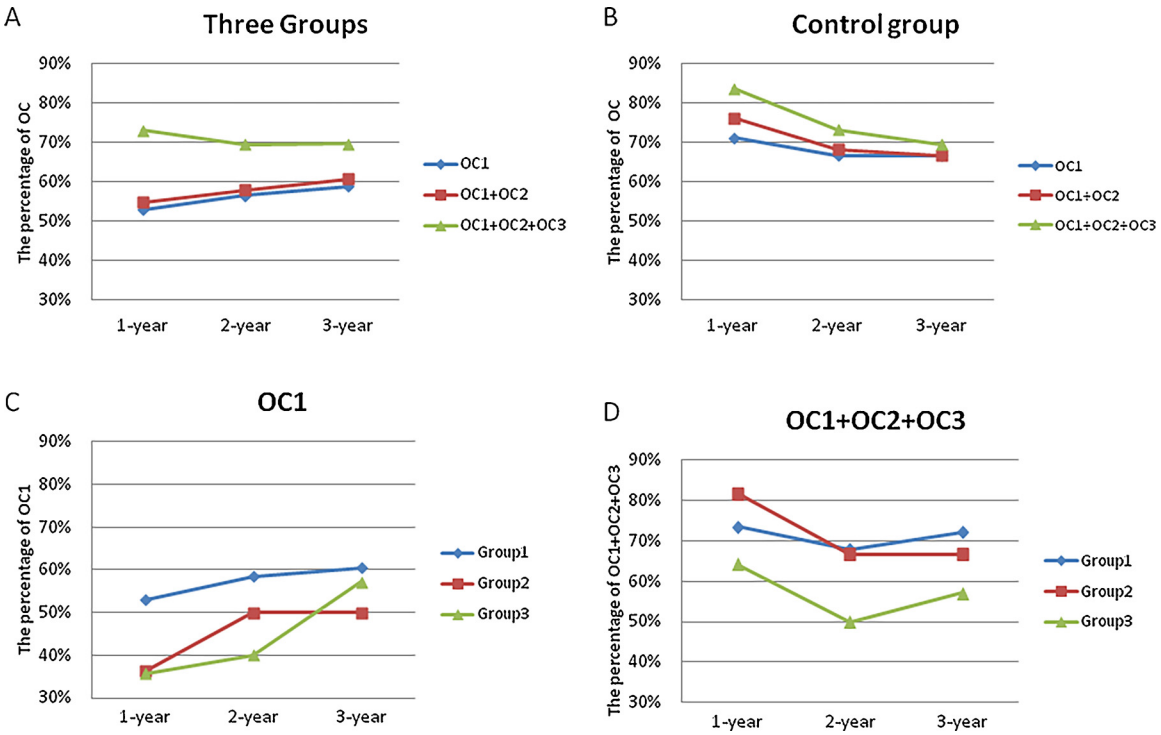

Fig. 2. The result of postsurgical follow-up. (A) The result of postsurgical follow-up for patients with BTLE. (B) The result of postsurgical follow-up for patients in control group. (C) The percentage of OC1 for patients with BTLE. (D) The percentage of OC1 + OC2 + OC3 for patients with BTLE.

Table 3
Comparison of outcome among different groups based on MRI finding.

OC1	G1 + 2 + 3		G1		G2		G3	P value (L vs. N)		
MRI	L	N	L	N	L	N	L	G1 + 2 + 3	G1	G2
Total	49.2%	33.3%	55.8%	36.0%	33.3%	20.0%	35.7%	0.15	0.115	0.621
1-year	52.4%	40%	60.5%	40%	33.3%	40%	35.7%	0.264	0.103	0.819
2-year	61.4%	48%	64.5%	50%	66.6%	0	40%	0.282	0.291	0.083
3-year	67.6%	42.1%	62.9%	43.8%	66.6%	0	57.1%	0.067	0.22	0.083

L-lesional MRI (including: L1-abnormal changes in unilateral or bilateral temporal lobes; L2-abnormal changes opposite the surgical site), N-non-lesional MRI (including: N1- no obvious abnormality; N2- abnomal changes in unilateral or bilateral extra temporal lobe), OC-outcome, G-Group.

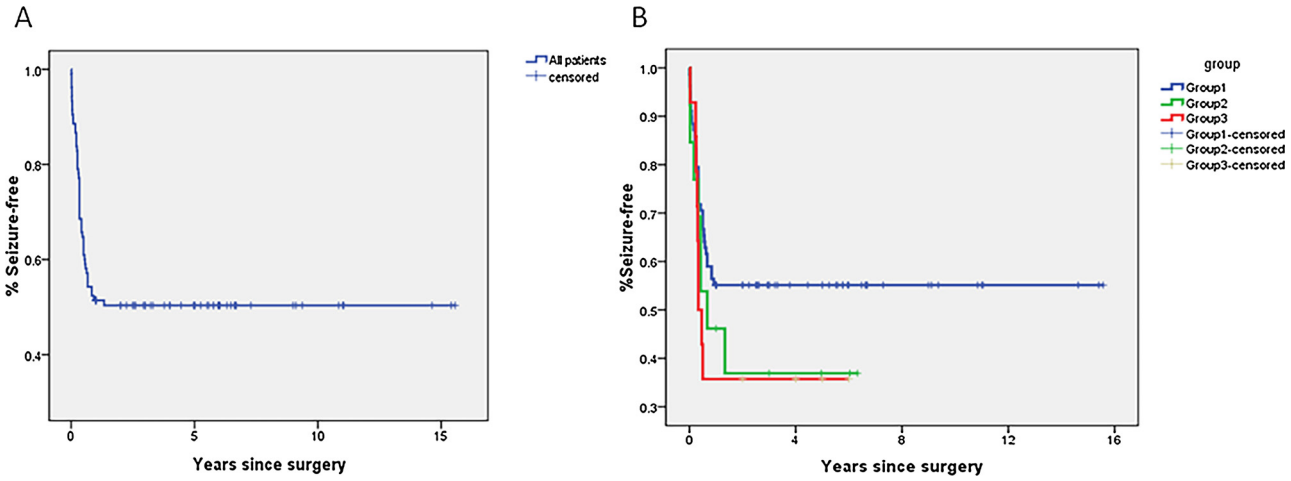

Fig. 3. Kaplan-Meier analysis of time to seizure recurrence. (A) Kaplan-Meier plot illustrating chances of postoperative seizure freedom in Group 1, Group 2, and Group 3. (B) Kaplan-Meier plot illustrating chances of postoperative seizure freedom according to different groups. The color significance of each score is shown in the top right corner of the figure.

35.7% (95%CI:11–61) for Group 3. Moreover, the survival analysis indicated that there was no difference in estimated proportion of patients remaining seizure free among Group 1, Group 2, and Group 3 ($p = 0.235$).

4. Discussion

4.1. Diagnosis

The clinical diagnosis of BTLE is still controversial. To some extent, the diagnosis depends on the evaluation method. A BTLE is initially suspected when most of the interictal discharges occur synchronously or occur independently with similar frequency bitemporally (Hirsch et al., 1991b). Usually, BTLE is diagnosed on the basis of the electroclinical manifestation of ictal scalp video-EEG. The scalp EEG findings of ambiguous or bitemporal seizure onset often lead to the diagnosis of BTLE. Patients with BTLE could be divided into two groups: patients with non-lateralizable bitemporal seizure and patients with independent bitemporal seizure (Aghakhani et al., 2014; Didato et al., 2015).

However, our study as well as some reports show that scalp video-EEG findings of ambiguous or bitemporal seizure onset are still weak predictors of actual BTLE (Liu et al., 2016; Loesch et al., 2015; Waseem et al., 2015). The ictal scalp video-EEG might not reflect the truth thoroughly. For example, the ictal electrical activity on the side of seizure onset might transmit rapidly to the contralateral temporal lobe at the initial period, or the seizure originates with low fast activities which could not be observed by normal scalp-EEG until the ictal activities gradually diffuse to the bilateral temporal lobes; therefore, bilateral or contralateral clinical symptoms appear first.

However, iEEG could often show these EEG details at the beginning of seizures, and localize the seizure generator to one temporal lobe (Aghakhani et al., 2014; Massot-Tarrús et al., 2016). More rigorous criteria of BTLE could include the findings of ictal intracranial recording, especially iEEG recorded by depth electrodes in bilateral hippocampus, which showed different seizures alternately arising from the two temporal lobes.

Nevertheless, EEG is not the only criteria in BTLE diagnosis. Abnormalities on MRI (e.g., hippocampal sclerosis or lesions) or PET was additional evidence. For example, BTLE might be considered when MRI shows the following manifestations: 1) obvious bilateral hippocampal sclerosis; 2) abnormal hippocampal signal in one temporal lobe, temporal atrophies in the other side; 3) hippocampal sclerosis in one temporal lobe, the contralateral amygdala is enlarged; and 4) hippocampal sclerosis in one temporal lobe, focal cortical dysplasia in the contralateral temporal lobe. Furthermore, occasionally, intracranial recordings showed the ictal onset dominantly originated from the opposite of the MRI abnormalities. It might be explained by the following reasons: 1) the limited seizure times that were recorded (King-Stephens et al., 2015); 2) the location of the intracranial electrodes was not optimal; 3) the limitation of the intracranial electrode that could not record the microcircuit on the initial part of the seizure; and 4) the underlying physical information, such as the high-frequency oscillations (HFOs), was not analyzed.

Pathological abnormality may be another explanation for the difficulty with the diagnosis of BTLE. Bilateral hippocampal sclerosis could often be found in the autopsy of patients with TLE, which might be associated with abnormal discharge of bilateral temporal lobes during the interictal period. The minor epileptogenic side might be easier to suppress with antiepileptic drugs (Hirsch et al., 1991b). As a result, drugs withdrawn during the long-term video-EEG monitoring may result in the contralateral seizure onset. However, whether bilateral temporal damage is a cause or a result of seizures is still controversial.

4.2. Surgical evaluation

Our study as well as some previous reports identified that scalp EEG findings of non-lateralizable or independent bitemporal seizure were not strong predictors of actual BTLE (Dubeau and McLachlan, 2000; Pacia and Ebersole, 1999). Ictal iEEG often identified that the seizures were generated from a unilateral temporal lobe. Therefore, surgery should not be excluded based on scalp EEG findings alone. IEEG might help to prove that many of these patients have unilateral seizure onset and are good surgical candidates. It is emphasized again by this study that a substantial proportion of patients (66.7%) presumed to have BTLE on scalp EEG actually have unilateral seizure onset on iEEG. The results of a meta-analysis of literature data on surgery outcome in 1403 patients with presumed BTLE on the basis of scalp EEG recordings showed that iEEG revealed 73% of the presumed BTLE patients actually have unilateral seizure onset, which was similar to our study (Aghakhani et al., 2014).

Occasionally, seizure onset was still undistinguishable between the two temporal lobes, even after the intracranial recording. In this condition, neuroimaging abnormalities would increase the weight of the side of the temporal lobe (Group 3), and the resection usually tends to the temporal lobe with abnormal neuroimaging. In our group, the MRI-positive lesions included hippocampal sclerosis, cavernous hemangioma, and tuberous sclerosis.

In addition, the recording of HFOs might be helpful in this condition (Dumpelmann et al., 2015). In our previous research (Liu et al., 2016), 13 patients who had been diagnosed with BTLE received iEEG recording by both conventional and wide-band frequency amplifiers after bilateral temporal lobe placement of intracranial electrodes. Ten patients recorded at least one seizure with wide-band frequency amplifiers. Unilateral ictal HFOs were recorded, and good surgical outcomes were achieved in these patients.

However, besides the identified unilateral temporal seizure onset, another important consideration should also be evaluated before surgery, and that is the function of the alternative side of the temporal lobe. Neuropsychiatric evaluation may help to learn the function of the alternative temporal lobe. The risk of neuropsychiatric deterioration was high if the other side of the lesional temporal lobe was the target of surgical resection. Neuromodulation might be a better choice in this condition.

4.3. Surgical outcome

The findings of this study showed that the surgical outcome of patients with BTLE was inferior to that of the patients with unilateral TLE identified by scalp EEG in a short-term follow-up (1 year after surgery). Further, the outcome of patients with actual unilateral seizure onset identified by iEEG was inferior to that of the patients in the control group as well. However, both of these two differences were not significant in longer follow-up (2 years and 3 years, respectively). Of course, it seems an unusual result. Some variations in the count, such as the recurrence, the running down phenomenon and the missing in follow-up, played compositive role in the OC1 ratio in the second and third year's follow-up. In total, more than 50% of patients with BTLE had an outcome of OC1 at the 1-year follow-up. The total ratio of patients who had the outcome of OC1 + OC2 + OC3 could achieve 73.1%, 69.5%, and 69.6% in 1 year, 2 years, and 3 years of follow-up, respectively. Moreover, the result of Kaplan-Meier analysis showed that there was no statistical difference in postoperative efficacy among Group 1, Group 2, and Group 3 one year after surgery. Therefore, the general surgical outcome for patients with BTLE was acceptable Similarly, in a systematic review that incorporated 1027 patients with suspected BTLE, 58% of patients were seizure free after ATL at 1 year follow-up, and 67% of patients could reach good outcomes (Engel's class I and II) (Aghakhani et al., 2014). We didn't find significant difference of the outcome in any group between patients with lesional MRI finding and non-lesional MRI finding.

Among the 39 patients with independent bitemporal seizure onset, 12 patients gave up surgical resection because of the similar portion of bilateral seizure onset. The outcome of the other 27 patients was also inferior to the control group at 1 year follow-up. Nevertheless, the difference was also not significant at the 2 years and 3 years follow-up. Moreover, in this study, although the outcome of patients with actual unilateral seizure onset was superior to that of patients with independent bitemporal seizures, there is no significant difference between these two groups in the postsurgical follow-up. Therefore, in selected patients with initially presumed BTLE, it is possible to obtain favorable outcome, even when the patients were confirmed as having BTLE. In addition, our results showed that the surgical outcome of patients with BTLE was relatively persistent in 3 years of follow-up.

4.4. Limitations

There are also some limitations in this study. This study is a review of the previous data. It has not included the data of patients who were diagnosed as BTLE and gave up surgical treatment after scalp video-EEG monitoring. Not all patients had PET, magnetoencephalogram examination, or neuropsychology evaluation; therefore, these supplementary data were not discussed. The number of patients with BTLE reviewed was relatively small and some patients were missed in the follow-up may also affect the result to some extent. In addition, the original data of laterality of memory and language functions was insufficient in this retrospective study. There is no comparison of the changes of language and cognitive function before and after the unilateral temporal lobectomy in this study. Whether the patients who have been confirmed as having BTLE would be at risk for severe postoperative decline in cognitive function after the unilateral ATL remains uncertain.

5. Conclusion

In summary, patients with BTLE who were diagnosed by scalp video-EEG should not be excluded for further presurgical evaluation. Intracranial recording can help to distinguish patients with unilateral seizure onset from patients with independent bilateral temporal seizures. Although the surgical outcome of patients with BTLE is not as good as that of patients with unilateral seizure onset in short-term follow-up, quite a portion of these patients could benefit from unilateral temporal lobe resection in the long term.

Disclosures

None of the authors has any conflict 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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Conflict of interest

The authors have no conflicts of interest to disclose.

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