

Ictal dipole source analysis based on a realistic scalp–skull–brain head model in localizing the epileptogenic zone

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Abstract

The objective of this study is to examine whether dipole modeling based on a realistic scalp–skull–brain head model (SSB/DT) is useful to localize the epileptogenic zone. Eight patients with surgically treated temporal lobe epilepsy were studied. Dipole locations and vector moments of ictal epileptiform activities were calculated by inverse solution methods. Accuracy of dipole locations were assessed by comparing with intracranial EEG. The patterns of ictal epileptiform activities were correlated with the dipole location and vector moment. Dipole locations of the peaks of ictal epileptiform activities estimated by SSB/DT showed good agreement with the epileptogenic foci determined by intracranial EEG. SSB/DT was able to discriminate between medial and lateral temporal epileptogenic foci. Two distinctive types of dipole vector moments, vertical and horizontal were noted. Vertical dipole vector moments corresponded to the medial temporal dipole source and horizontal dipole vector moments were corresponded to the lateral temporal dipole source. Useful clues to differentiate between medial and lateral temporal lobe epilepsy by the visual inspection of scalp EEG were found. SSB/DT is useful tool in the presurgical evaluation of patients with intractable epilepsy.

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1. Introduction

Localization of the epileptogenic focus is the goal of preoperative examination of epilepsy surgery. In considering the localization methods, intracranial EEG is understood as a ‘gold standard’. However, intracranial EEG does not always succeed in localizing epileptogenic foci and associated morbidity is inevitable. In such occasions, supportive or alternative non-invasive procedures are necessary. Among the non-invasive localization techniques under investigation, dipole source analysis and its precursor, voltage topography, are particularly promising (Ebersole and Wade, 1991). Since the accuracy of dipole source analysis depends on the amplitude of the generator sources

(Krings et al., 1999), ictal epileptiform activity is a suitable subject of investigation (Assaf and Ebersole, 1997). Moreover, ictal epileptiform activity is believed to be more reliable than interictal activities in localizing epileptogenic foci (Badier and Chauvel, 1997; Jayakar et al., 1991). As the technique shows promise, its results should be compared with those from patients who have been examined by intracranial EEG (Boon et al., 1996). In this study, we validated the accuracy and usefulness of dipole tracing method of the realistic scalp–skull–brain head model (SSB/DT) (Homma et al., 1994, 1995; Mine et al., 1998a, 1998b) applied to the ictal epileptiform activity by correlating those results with that of intracranial EEG. We also examined the following issues important in using SSB/DT to analyze ictal epileptiform activity; patients’ movements or artifacts which make the data difficult to interpret and the ability of SSB/DT to discriminate between medial and lateral temporal lobe

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epilepsy. In order to evaluate the benefits of SSB/DT, we performed ictal dipole source analysis in patients with intractable temporal lobe epilepsy, who underwent intracranial EEG and focus resection.

2. Materials and methods

2.1. Clinical features of the patients (Table 1)

Eight patients, six males and two females, with a mean age of 33 years (range 20–54 years) were involved in the study. A mean duration of epilepsy was 17 years (range 5–33 years). Patients were selected from a larger patient population admitted to the Chiba University Hospital, Department of Neurosurgery between 1997 and 2000. All patients suffered intractable temporal lobe epilepsy (TLE) and underwent focus resection. Five patients (patients 1, 3, 4, 6 and 8) had TLE of medial temporal lobe origin and three patients (patients 2, 5 and 7) had TLE of lateral temporal lobe origin. These patients had been investigated by a prolonged video-EEG monitoring with scalp electrodes to record ictal epileptiform activities, high resolution magnetic resonance imaging (MRI), interictal measurement of cerebral glucose metabolism by ^{18}F -deoxyglucose positron emission tomography (FDG-PET), interictal measurement of regional cerebral blood flow using a $^{99\text{m}}$ Technetium ECD ($[N,N'$ -ethylene di-L-cysteinate (3-)]oxotechnetium ($^{99\text{m}}\text{Tc}$), diethyl ester) single photon emission computed tomography (ECD-SPECT), and neuropsychological evaluation. MRI revealed hippocampal atrophy in patients 1, 4 and 6, intraaxial tumor in patient 8, no organic lesion in patients 2, 3, 5 and 7. Interictal ECD-SPECT revealed localized hypoperfusion in patients 1–6 consistent with the primary epileptogenic zone. Interictal FDG-PET revealed

localized glucose hypometabolism in patients 2–8 consistent with the primary epileptogenic zone. When results of these multidisciplinary examinations indicated a single epileptogenic focus, focus resection was performed following prolonged video-EEG with chronic subdural electrodes in five patients (patients 1–5) following intraoperative electrocorticography (ECoG) in three patients (patients 6–8) without chronic subdural prolonged video-EEG. Chronic subdural EEG recording was performed except in patients who underwent standard temporal lobectomy and amygdalohippocampectomy on the non-dominant side. Placement of subdural electrodes (ADTECH, Wyler subdural electrode) was determined by referring to the result of ictal scalp EEG and the intraoperative ECoG. Care was taken not to miss the area generating ictal epileptiform activities. Intraoperative photographs were taken to record the brain structure and placement of subdural electrodes. When the epileptogenic focus was localized around the speech area, functional mapping was performed by electrical stimulation of the cortex. The surgical procedures were selective amygdalohippocampectomy in patients 1, 3 and 4, selective amygdalohippocampectomy with tumor extirpation in patient 8, anterior temporal lobectomy in patients 2 and 7, anterior temporal lobectomy with amygdalohippocampectomy in patient 6, corticectomy of lateral temporal cortex and multiple subpial transaction in patient 5. The procedures were determined according to the location of epileptogenic focus. The pathological diagnosis of the resected tissue was hippocampal sclerosis in patients 1, 4 and 6, cortical dysplasia in patients 2 and 5, gliosis in patients 3 and 7, and astrocytoma grade 2 in patient 8. Surgical outcomes were satisfactory; Engel Class Ia in patients 2, 4 and 8, Ib in patients 1 and 3, IIa in patients 5–7. A follow-up period was from 37 to 70 months with an average of 54.0 months.

Table 1
Patient characteristics

Patient/ sex/age	Seizure type	Epilepsy duration	Primary epileptogenic zone	MRI	Interictal ECD-SPECT	Interictal FDG-PET	Surgery	Pathology	Outcome (follow-up month)
1/M/20	CPS	5	L medial temporal	L hippocampal atrophy	L temporal	NA	Selective AHTomy	HS	Ib (37)
2/M/23	CPS, 2nd GTCS	9	R lateral temporal	No lesion	R temporal	L temporal	ATL and corticectomy	Cortical dysplasia	Ia (51)
3/M/34	CPS	17	L medial temporal	No lesion	L temporal	L temporal	Selective AHTomy	Gliosis	Ib (39)
4/M/34	CPS	33	L medial temporal	L hippocampal atrophy	L temporal	L temporal	Selective AHTomy	HS	Ia (54)
5/F/27	CPS, 2nd GTCS	17	L lateral temporal	No lesion	L temporal	L temporal	Corticectomy and MST	Cortical dysplasia	IIa (70)
6/M/31	CPS, 2nd GTCS	20	R medial temporal	R hippocampal atrophy	Bt temporal	Bt temporal	ATL and AHTomy	HS	IIa (67)
7/M/25	CPS	15	R lateral temporal	No lesion	NA	L temporal	ATL	Gliosis	IIa (63)
8/F/47	CPS, 2nd GTCS	20	R medial temporal	R medial temporal tumor	NA	R temporal	Tumor removal and AHTomy	Astrocytoma grade 2	Ia (51)

M, male; F, female; CPS, complex partial seizure; 2nd GTCS, secondarily generalized tonic clonic seizure; L, left; R, right; epilepsy duration is indicated by years; interictal EDC-SPECT indicates the area of the brain with reduction of regional cerebral blood flow; interictal FDG-PET indicated the area of the brain with reduction of regional glucose metabolism; NA, not available; ALT, anterior temporal lobectomy, AHTomy, amygdalohippocampectomy; MST, multiple subpial transaction; HS, hippocampal sclerosis; outcome in September 2003.

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