Localization of epileptogenic zone in temporal lobe epilepsy by ictal scalp EEG

YUZO SAKAI†, HIROMI NAGANO†, AYUMI SAKATA†, SACHIKO KINOSHITA†, NAOTAKA HAMASAKI†, FUMIO SHIMA‡ & TAKATO MORIOKA§

†Department of Clinical Chemistry and Laboratory Medicine, Kyushu University Faculty of Medicine; Departments of ‡Clinical Neurophysiology and §Neurosurgery, Graduate School of Medical Sciences, Kyushu University

Correspondence to: Takato Morioka, MD, PhD, Department of Neurosurgery, Graduate School of Medical Sciences, Kyushu University, 3-1-1 Maidashi, Higashi-ku, Fukuoka 812-8582, Japan. E-mail: takato@ns.med.kyushu-u.ac.jp

Our aim was to evaluate the ability to localize the epileptogenic zone in temporal lobe epilepsy (TLE) by ictal scalp electroencephalogram (EEG). Using simultaneous video recording, we analysed scalp EEG activity during ictal periods in 38 patients (30 patients with medial TLE (MTLE) and eight with lateral TLE (LTLE)). In 14 patients, intracranial ictal EEGs were recorded with depth electrodes, and simultaneous recordings of scalp and intracranial EEG were performed in 11 patients. Scalp EEG showed that, in all 30 patients with MTLE (71 of 72 seizures), an attenuation of background activity was observed before the appearance of ictal activity. Ictal discharges first appeared in the scalp EEG when the ictal discharges reached the lateral part of the temporal lobe on the intracranial EEG. While, in all eight patients with LTLE (25 of 25 seizures), the attenuation of background activity did not occur before the appearance of ictal activity. When the ictal discharges started in the lateral temporal lobe on intracranial EEG, ictal discharges appeared on the scalp. MTLE and LTLE could be diagnosed by the presence or absence of attenuation of background activity with clinical ictal signs before the appearance of ictal discharges.

Key words: temporal lobe epilepsy; EEG; epileptogenic zone.

INTRODUCTION

To localize the epileptogenic zone for surgical treatment of intractable temporal lobe epilepsy (TLE), neuroimaging such as magnetic resonance image (MRI), single photon emission tomography (SPECT), positron emission tomography (PET) and electrophysiological examinations such as EEG and magnetoencephalography are considered very important. Among them, invasive intracranial EEG recording using depth and subdural grid electrodes is the gold standard to determine the dynamics of epileptic seizures from the onset to propagation. Although sites of intracranial EEG measurement are determined by scalp EEG and neuroimaging, the setting of intracranial electrodes at more than one site is sometimes necessary due to difficulties in localizing the epileptogenic area with non-invasive methods. However, it is difficult to record all EEG activity in the bilateral temporal lobes and surrounding cortical areas because the number of EEG channels is limited. Furthermore, intracranial EEG measurement is a burden on patients because of its invasiveness. Therefore, if the epileptogenic zone (medial or lateral, right or left) can be detected by scalp EEG, placement sites for the intracranial electrodes can be chosen, or even avoided under some circumstances1–4. Studies of localizing the epileptogenic zone by scalp EEG have been conducted, but no appropriate diagnostic method has yet been established.

In this study, we analysed scalp and intracranial EEG activity during ictal periods together with videorecordings of patients with intractable TLE who had undergone surgery, and evaluated the ability of ictal scalp EEG to diagnose the epileptogenic zone.

SUBJECTS

The subjects were 38 patients who had been diagnosed by clinical observation, CT, MRI, SPECT, PET and surgical observation as having medial TLE (MTLE) (30 patients) and lateral TLE (LTLE) (eight patients). The age of the patients ranged from 13 to 45 years.
old (22 males, 16 females). In all patients, epileptic surgery had been performed, after chronic depth and subdural recordings, and seizures disappeared or were reduced during post-operative observation.

METHODS

Electrodes for EEG recording on the scalp were placed on lower temporal and upper facial regions, such as the anterior and posterior earlobes and upper and lower eyelids, in addition to electrodes on the scalp for the 10–20 placements and sphenoidal leads. EEG activity was recorded using a digital EEG recorder (Neurofax, Nihon Koden, Tokyo).

Images of the entire body and face of patients were recorded using a high resolution video recorder and displayed simultaneously with the EEG on a screen. The relationship between the characteristics of clinical behaviour and EEG activity were evaluated in all patients. Analysis of EEG activity was performed using the scalp electrode distant from the region of interest as the common reference electrode. Amplification sensitivity and filter settings were changed when necessary. When either of the following conditions was observed in the changes in the EEG activity at the time of seizures, it was regarded as attenuation of background activity:

1. the amplitude of background activity was reduced by more than 50%, and continued for longer than 2 seconds;

2. the attenuation of background activity showed the same pattern of changes as in EEG activity on waking, on eye opening or when tense, and this attenuation continued for longer than 2 seconds.

In 14 patients (11 patients with MTLE, three patients with LTLE), depth electrodes were inserted into the bilateral hippocampus and amygdala through burr-holes, and placed at intervals of 1–2 cm up to the surface of the lateral cortex. In the other 24 patients (19 patients with MTLE, five patients with LTLE), subdural grid electrodes were placed on the medial, basal and lateral aspects of both (four patients) or one (20 patients) temporal lobe through a craniotomy. In 11 cases (eight patients with MTLE, three patients with LTLE), simultaneous recording of scalp and intracranial EEG was performed.

RESULTS

On intracranial EEG with depth electrodes, 42 ictal discharges were obtained. Twenty-eight and 14 ictal discharges were recorded in MTLE and LTLE, respectively. Figure 1 summarizes the propagation of these 42 ictal discharges. In MTLE, 10 remained within the medial part of the temporal lobe ipsilateral to the ictal onset, which arose either from the hippocampus to the amygdala or from the amygdala to the hippocampus, eight propagated to the ipsilateral lateral part of the temporal lobe, four to the contralateral medial part, three to both the contralateral medial and the ipsilateral lateral parts, and three discharges were propagated to the contralateral lateral part via the contralateral medial part and finally reached the bilateral lateral parts. No discharges were directly propagated from the medial to the contralateral lateral part. In LTLE, eight were propagated to the ipsilateral lateral part and six to the ipsilateral medial part.

On the scalp EEG, 97 seizures were obtained, 72 and 25 were recorded from MTLE and LTLE, respectively. The attenuation of background activity occurred before the appearance of ictal discharges on the scalp EEG in all 30 patients with MTLE (71 of 72 seizures) (Fig. 2). This attenuation sometimes occurred continuously, but often occurred at intervals. During these periods, changes in behaviour that were clearly inappropriate to the circumstances (akinesia, staring, movement of hands/feet, changes in respiration, straining, oral automatism, eye blinking, phonation, opening and closing eyes, soliloquy, discontinuation of conversation, changes in a look, automatism of four limbs, complaints) were observed. These clinical ictal signs were observed within 2 seconds after the start of the attenuation of EEG activity in 22, and within 10 seconds in 48 of the 72 seizures. During these periods, epileptic discharges in the medial part were confirmed by simultaneous intracranial and scalp EEG in all 11 patients (25 of the 25 seizures) (Fig. 2). Rhythmic ictal discharges first appeared on the scalp EEG when the ictal discharges reached the lateral part of the temporal lobe on intracranial EEG (Fig. 2).

In all eight patients with LTLE (25 of 25 seizures), there was no attenuation of background activity before the appearance of ictal waves on the scalp EEG (Fig. 3). The clinical ictal signs were observed within 2 seconds after the appearance of rhythmic waves on the scalp EEG in 19 seizures and within 6 seconds in all of the 25 seizures. The clinical symptoms were similar to those of MTLE. When the ictal discharges started on the lateral part of the temporal lobe in the intracranial EEG, rhythmic ictal discharges appeared on the scalp EEG (Fig. 3).

Ictal discharges on the scalp EEG were localized rhythmic waves in most seizures in both MTLE (68 of 72 seizures) and LTLE (20 of 25), in which all ictal onset parts were clear. In other seizures (six of 72 in MTLE and five of 25 in LTLE), ictal discharges were generalized rhythmic waves, in which ictal onset...
Ictal EEG in TLE

Fig. 1: Propagation of intracranial ictal discharges: ●: medial onset, ○: lateral onset, △: propagated side. Numerals indicate the numbers of ictal discharges (total 42).

Fig. 2: Simultaneous recording of scalp and intracranial EEG during the ictal period in a patient with medial temporal lobe epilepsy (common reference on A1). When ictal discharges started in the hippocampus (Hip(0)), scalp EEG activity was suppressed. Automatism of the left upper limb started 15 seconds later, and ictal rhythmic waves appeared in Fp2, F4, and F8 of the scalp when the ictal discharges reached the lateral cortex (Cx) of the temporal lobe. Hip(1), Hip(2), Hip(4) and Hip(5) were 1, 2, 4 and 5 cm distant from the hippocampus toward the cortex (Cx), respectively. Amg: amygdala.

parts and sides were not clear. The ictal discharge occurred in all regions where interictal localized paroxysms and slow waves occurred and in regions where no abnormalities were observed.

The frequency of rhythmic waves at ictal onset that was most often observed in MTLE was the theta band (Table 1). However, rhythmic waves of various frequencies were observed in both MTLE and LTLE, and there were no characteristic frequencies.

In 34 out of 97 seizures (35%), the ictal onset parts coincided with the regions where the localized ictal waves persisted after the cessation of the clinical seizure. In 40 seizures (41%), ictal discharges that newly occurred during the ictal period remained.
Fig. 3: Simultaneous recording of scalp and intracranial EEG during the ictal period in a patient with lateral temporal lobe epilepsy (common reference on Cz). There was discharge from the temporal lateral cortex (Cx), and simultaneously, ictal rhythmic waves appeared from T3 of the scalp, without a decrease in the scalp EEG background activity.

Ictal discharges simultaneously disappeared after generalization in 20 (24%).

Table 1: Frequency of ictal activities.

<table>
<thead>
<tr>
<th>Frequency of ictal activities</th>
<th>MTLE (Number of seizures)</th>
<th>LTLE (Number of seizures)</th>
</tr>
</thead>
<tbody>
<tr>
<td>β</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>α</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>θ</td>
<td>30</td>
<td>2</td>
</tr>
<tr>
<td>δ</td>
<td>19</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>66</td>
<td>20</td>
</tr>
</tbody>
</table>

DISCUSSION

Conventionally, MTLE and LTLE are distinguished by the clinical symptoms of seizures, but the efficacy of this method is limited because it is rare to encounter a typical seizure pattern of MTLE, such as oral automatisms, pupillary dilatation and generalized rigidity. Maldonado et al. reported that seizures showing an akinetic stare or oral automatisms originated in the hippocampus, amygdala or most commonly both. Whereas Hiyoshi et al. considered that an akinetic stare is not necessarily a sign of seizures and does not originate from the hippocampus, but rather is a state of very low responsiveness due to the spread of epileptic discharge to the entire bilateral cerebral hemisphere. We also found many characteristic pre-ictal signs and early expression of seizures that are common to both MTLE and LTLE, and could not identify a specific feature in either of them.

Our observation of epileptic discharge propagation by intracranial EEG indicated that epileptic discharges originating from the medial part often propagated to the contralateral medial part, and that discharges are also propagated from each medial part to the ipsilateral lateral part. Goto et al. showed that epileptic discharges originating from the medial part are not directly propagated to the lateral region on the opposite side, but indirectly via the hippocampal commissure and hippocampus on the opposite side in rats. We confirmed their observation clinically.

This paper revealed that, in MTLE, the attenuation of the background activity on scalp EEG soon after the initiation of an ictal discharge in the medial temporal part on intracranial EEG was followed, mostly within 10 seconds, by signs of a seizure, such as motionless, staring, oral automatism, body movement and soliloquy. Rhythmic ictal discharges first appeared on the scalp EEG when the ictal discharges reached the lateral part of the temporal lobe on intracranial EEG, and the seizure expression further advanced. On the contrary, in LTLE, when an ictal discharge started in the lateral part of the temporal lobe
on intracranial EEG, rhythmic ictal waves appeared on scalp EEG without a decline of background activity, and was followed by clinical ictal symptoms within 2 seconds. Therefore, it seems possible to distinguish MTLE from LTLE based on these facts. Although previous authors also demonstrated that the first EEG change of TLE is frequently a widespread attenuation of background activity, they did not refer to the physiological significance of this electrical phenomenon.

Since the decline of the background activity was not always persistent, being indistinguishable from ‘alpha attenuation’ due to eye opening, we speculate that this is due to a feeling of mental or physical disorder or movement of the body which is caused by a seizure induced by a discharge in the medial temporal lobe, rather than the spread of the ictal discharge to the deeply situated midline structures such as brainstem and bilateral thalamus.

Ebersole et al. showed that the rhythmic waves of 5–9 Hz that are first seen in the temporal region during seizures are specific to MTLE. We also found that waves of the theta band were most abundant in MTLE, but also found rhythmic waves of various frequencies from the delta to beta band in both MTLE and LTLE, indicating that these are not specific to MTLE.

It has been assumed that epileptogenic areas are likely to be present on the side where spontaneous rhythmic waves appear upon the occurrence of seizures, and this is still an important clue for lateralizing the epileptogenic focus. In relation to the propagation of ictal activity on the intracranial EEG, discharges originating in the medial part are propagated to the lateral part on the same side to induce discharges, and also induce discharges in the lateral part on the opposite side via the contralateral medial part. Because of the delay caused by this propagation pattern, prediction of the origin of the discharges by scalp EEG has a reasonable basis. However, the latency in the lateral part ipsilateral to the origin is sometimes the same as or longer than that contralateral to the origin, resulting in earlier discharges on the latter side, so that the side showing the leading ictal activity is not necessarily the side of epileptic origin. Inoue et al. reported that in 58 patients in whom the side of origin was identified by intracranial EEG, five showed scalp EEG that would indicate opposite predictions. They also indicated that such a discrepancy could be minimized by examining many ictal events.

In this paper, the region of residual localized ictal waves on the scalp immediately after the cessation of the seizure does not necessarily correspond to the epileptogenic area, since the residual region is determined by the magnitude and timing of the occurrence of discharge.

In conclusion, scalp EEG activity during the ictal period could provide information with which differentiation between MTLE and LTLE can be deduced with high accuracy. However, they provide an incomplete assessment of laterality in MTLE.

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REFERENCES


