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Original article

Detection of fast (40–150 Hz) oscillations from the ictal scalp EEG data of myoclonic seizures in pediatric patients

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Abstract

Objective: We explored fast (40–150 Hz) oscillations (FOs) from the ictal scalp electroencephalogram (EEG) data of myoclonic seizures in pediatric patients to obtain insight into the pathophysiological mechanisms involved in the generation of myoclonic seizures.

Subjects and methods: The participants were 21 children (11 boys, 10 girls; age ranging from 5 months to 17 years 2 months) with myoclonic seizures associated with generalized (poly)spike-wave bursts in the ictal EEG data. The patients had heterogeneous etiologies and epilepsy diagnoses. In the ictal data, we detected FOs that clearly showed oscillatory morphology in filtered EEG traces and an outstanding spectral blob in time-frequency analysis.

Results: We identified FOs in 61 (88.4%) of all 69 myoclonic seizures. Every patient had at least one myoclonic seizure-associated FO. The observed FOs were embedded in the spike component of (poly)spike-wave discharges, and they had a focal distribution with frontal predominance. They ranged in frequency from 41.0 to 123.0 Hz and involved both the gamma and ripple bands, and their spectral peak frequencies were higher in the group of patients with a genetic background free of apparent fundamental brain pathology than in the group of other patients ($p = 0.019$).

Conclusion: FOs were found to represent at least part of the cortical pathophysiological process in the generation of myoclonic seizures that should involve the thalamocortical network system.

Keywords: High-frequency oscillations; Fast oscillations; Childhood epilepsy; Myoclonic seizure; Spike-wave; Ictal EEG

1. Introduction

Myoclonic seizure is one of the cardinal seizure types in various pediatric epileptic syndromes including Dravet syndrome, epilepsy with myoclonic-atonic seizures (Doose syndrome), and Lennox-Gastaut syndrome (LGS). Clarification of the pathophysiology of myoclonic seizures should provide some valuable insight into the pathogenic mechanisms of these epileptic disorders, particularly epileptic encephalopathies.

Pathological high-frequency oscillations (HFOs) including ripples (80–200/250 Hz) and fast ripples (200/250–500 Hz) have been shown to be related to

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epileptogenesis, having an even closer relationship to epileptogenicity and ictogenicity than do epileptic spikes [1,2]. Fast oscillations (FOs) including gamma (40–80 Hz) and ripple oscillations were shown to be recordable over the scalp as slower correspondence of intracranial HFOs [3–6].

Detection of FOs from the ictal scalp electroencephalogram (EEG) data of myoclonic seizures is challenging because of the difficulty of obtaining clean data due to a tendency of heavy contamination from muscle activity and/or motion artifacts, and the detection of these FOs is so far unreported to the best of our knowledge. However, the characteristics of ictal FOs, if existent, associated with myoclonic seizures would provide valuable information on the nature of myoclonic seizures. Questions with regard to the characteristics of FOs include the following: Q1) Are the ictal FOs associated with the spike-component as in the case of rolandic spikes [7–9] or the slow-wave component as in the case of the ictal EEG data of epileptic spasms [4,10,11]? Q2) Are the ictal FOs distributed diffusely as in the case of associated (poly)spike-wave bursts or focally as in the case of FOs in infantile spasms [12]? Q3) Are the ictal FOs dominant in the gamma or ripple or both frequency bands? To help answer these questions, we hope to explore FOs from the ictal EEG data of myoclonic seizures.

2. Methods and subjects

2.1. Subjects

The subjects of the present study were 21 pediatric epileptic patients (11 boys, 10 girls) with myoclonic seizures that were confirmed by ictal video-EEG recording between January 2005 and July 2017 at Okayama University Hospital. Ages at the time of EEG recording ranged from 5 months to 17 years 2 months (mean 6.0 years). According to the classification of epileptic seizures published in 1981, myoclonic seizures were defined as epileptic seizures characterized by sudden, brief, shock-like contractions [13]. Although myoclonic seizures with a focal onset are now recognized [14], the present study included only apparently generalized myoclonic seizures that were associated with generalized (poly)spike-wave bursts in the ictal EEG. Our cohort was limited to patients with at least one ictal scalp EEG record of myoclonic seizure with no or only minimum artifacts and associated brief electromyogram (EMG) activity from deltoid muscles. Diagnoses and etiology of the patients were heterogeneous, and their demographic data are listed in Table 1.

This study was approved by the Okayama University Ethics Committee.

2.2. Methods

EEG was recorded with a sampling frequency of 500 Hz using a Nihon-Kohden (Tokyo, Japan) Neurofax system. The international 10–20 electrode system was used, and the analysis was performed in a referential montage, using the average EEG of the earlobes (A1 and A2) as a reference (indicated as Aav). The ictal scalp EEG data of myoclonic seizures associated with deltoid muscle jerks were first reviewed to select clean data (e.g., Supplementary Fig. 1 top). EEG data were subsequently investigated through temporal expansion of the traces with low-cut frequency (LCF) filters at 40 and 80 Hz (e.g., Fig. 1A; LCFs at 0.5, 40, and 80 Hz in green, blue, and red traces, respectively).

FOs were examined through time-frequency power spectral analysis of the ictal EEG data using the Gabor transform, which is the Fourier transform with a sliding Gaussian window of 50-ms full-width half-maximum (FWHM). Spectral analysis was performed in each of the following channels: Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T3, T4, T5, T6, Fz, Cz, and Pz, with reference to Aav (e.g., Supplementary Fig. 1 bottom). An FO spectral peak was identified as an outstanding spectral blob with a frequency above 40 Hz (spectral criterion). The width of each spectral segment was 1000 ms, and the frequency ranged from 20 to 150 Hz. The Fourier transform was performed on 256 data points (512 ms; frequency resolution 1.95 Hz) at each 2-ms time step. Computation was performed using a program written in-house for MATLAB (version 7.5.0; MathWorks Inc., Natick, MA, USA) in conformity with our previous studies [3,4,7].

In the panels of time-frequency analysis of all channel-data, the channel showing the clearest FO spectral peak was selected for further analysis to confirm if the detected peak was actually associated with clear morphological oscillations defined as an event of at least four consecutive oscillations in the LCF filtered traces (waveform criterion) (e.g., Fig. 1B).

In all of the ictal EEG data, the detected FO, if any, was investigated regarding its spectral peak frequency and power, the electrode of observation, and the latency from the onset of FO in the filtered EEG trace to the onset of deltoid muscle activity in EMG (the earliest muscle jerk in the case of a midline FO, and the contralateral muscle jerk in the case of a lateralized FO). When there was more than one FO in a seizure, the clearest FO in terms of the spectral and morphological patterns was selected for the analysis. When there were multiple equally clear FOs in a seizure, that with the highest spectral peak frequency was selected (Fig. 2).

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