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Lesion localization algorithm of high-frequency epileptic signal based on Teager energy operator

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ABSTRACT

High-frequency oscillations reflect the abnormal brain electrical activity in patients with epilepsy. It is significant to research the relationship between high-frequency oscillation and epilepsy originating area for the diagnosis and treatment of epilepsy. In view of the identification of epileptic EEG and the location of epileptic foci, a localization algorithm based on Teager operator is proposed. Firstly, the original epileptic EEG data are preprocessed, the wavelet weighted threshold and the frequency notch method are used to denoise the original epileptic high frequency oscillation signal. Taking into account the frequency characteristics of the high frequency oscillating signal itself, the FIR (Finite Impulse Response) digital filter is used to filter the epileptic high-frequency oscillation signal. Secondly, because the high frequency oscillation rhythm has the characteristics of high frequency, high energy and low amplitude, the Teager energy operator and curve length method are used to extract the characteristics. The PSD (Power Spectral Density) method is applied to qualitative analysis of epileptic lesion location. Finally, the EMD (Empirical Mode Decomposition) algorithm is used to decompose the high-frequency oscillation signal. Combined with Teager energy operator, Teager-huang transform is used to analyze the signal by time-frequency energy analysis. Quantitative analysis of epileptic lesion location is made by using EMD energy entropy method for different lead epileptic signals. The algorithm can effectively locate the location of the focus, independent of individual parameters and high degree of automation. It has good clinical application prospects.

1. Introduction

The annually incidence of epilepsy is 50–70 in 100,000 people every year, and the prevalence rate is 0.5% to 2%. It is estimated that 1 to 2 percent of the US population suffers from epilepsy [1], and in a large-scale survey organized by the World Health Organization shows that the prevalence rate is about 8% in China. This means that there are about more than ten million epilepsy patients [2,3], in which there are about 2.5 million intractable epilepsy patients. Epilepsy is already a deadly disease which is only second to cerebrovascular disease in neurological diseases [4]. It has great significance to study various abnormal EEG for the diagnosis and treatment of epilepsy [5].

Currently, the research for epilepsy EEG is mostly concentrated in the frequency band below 100 Hz. The study shows that, before and after the seizures of epilepsy, a higher frequency band signal which is acquired by intracranial electrode can be found in EEG with a high sampling rate [6], and the signal is known as high-frequency oscillation (HFO) rhythm. It is closely related to seizures [7], reflecting the important features of abnormal EEG signals during seizures [8,9]. Among the EEG, the oscillation rhythm whose frequency range from 80 to 200 Hz is called ṙippleș can be regarded as a normal HFO rhythm [10]. The oscillation signals more than 200 Hz frequency are usually considered as pathological HFO rhythm, which is closely linked to abnormal EEG and physiological changes produced during the seizures [11]. The oscillation signal including the frequency range of 200–600 Hz called “fast ripples” (FRS) and frequency range of 1000–2500 Hz called “very high frequency oscillations” (VHFO) [12].

The major difference between pathological HFO and normal HFO, is the different parts of its occurrence. The normal HFOs are unlikely to appear in dentate gyrus structure [13,14]. In the

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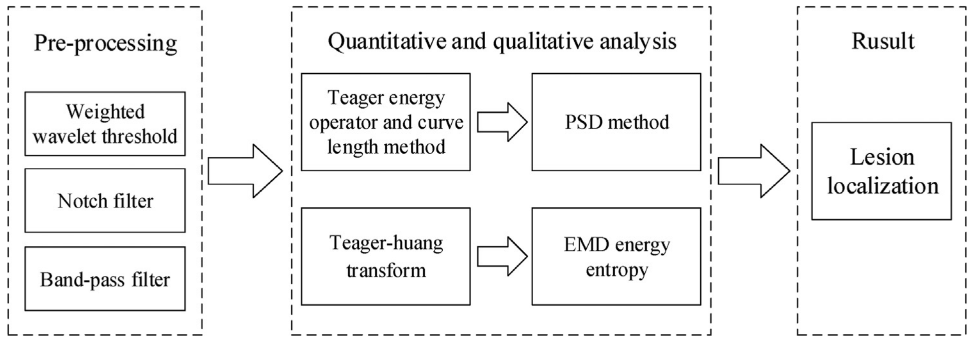

Fig. 1. Algorithm ideas.

presence of seizures, accompanied by the production and spread of HFOs. In seizures, usually with the generation and spread of HFOs. When the motor cortex of the brain is affected, it shows the patient's local movement symptoms, which is the so-called clinical manifestations [15]. During the period of seizures, HFO have a specific distribution, which is the occurrence frequency of HFO. Usually increasing from outside to inside in epilepsy originating area, especially FRS, the closer to the epileptic foci core area, the higher frequency FRS is recorded [16]. From the perspective of time, there is a diffusion process which the HFOs spread from inside to outside during the seizures period, while in terms of space, the closer to the epileptic foci originating area, the higher frequency FRS will be recorded [17]. The research for VHFO started late, and because of its very high frequencies and difficult to acquisition, now the study of high-frequency oscillation signal mainly concentrated on the ripples and FRS [18].

Many scholars have stated exploratory research on high frequency oscillation analysis algorithms. Zelmann used high sampling rate of 2000 Hz, with a 500 Hz low pass filter to obtain the frequency characteristics of ripples and fast ripples present in EEG during an epilepsy episode [19]. This was then combined with wavelet transform entropy and energy feature extraction to obtain the high frequency oscillation rhythm [19]. Smart et al. used high-precision multi-lead (64 leads) EEG to acquired epileptic EEG data from a plurality of epilepsy patients, and through analysis with high-pass filter and data segmentation method were able to detect the characteristic wave of ripples in HFO rhythm [20]. Chaibi et al. cooperate with Montreal Neurological Institute in Canada, used high sampling rate of 2000 Hz to obtained epilepsy EEG data, and designed a software based on MATLAB to detect the high-frequency oscillation rhythm automatically by matching tracking method [21].

Staba et al. at the University of California collected a series of high-frequency oscillation signals with intracranial electrodes at a sampling rate of 10 KHz. The acquired signal contains 16-leads, and the frequency of the signal ranges from 0.1 Hz to 5 KHz. Therefore, the signal contains various components of high-frequency oscillating rhythm, such as ripples, fast ripples, etc. In order to extract the high-frequency oscillation signal corresponding rhythm band, Staba et al. used a FIR band-pass filter in the 80 to 200 Hz range and nonlinear fitting Lorentz distribution method to get ripples rhythm from the background signal [22]. Makeyev et al. used hardware filtering method to obtain ripples and fast ripples rhythm signals from epilepsy patients and Laplace transform to extract high-frequency oscillation rhythm [23]. Allison et al. analysed the high-frequency oscillation data during seizures. According to the morphological characteristics of the high-frequency oscillation rhythm of epileptic seizures, the high-frequency oscillatory rhythm feature extraction was performed by three methods: support vector machine, K nearest neighbour, and logistic regression [24]. Jose et al. also used the high sampling rate of 20 KHz to acquire the 16-lead high-frequency oscillation signal. After the FIR band-pass filter was used to obtain the fast ripples signal of the corresponding frequency band, the Hilbert transform method was used to obtain the high-frequency oscillation signal [25].

At present, the study of high-frequency oscillation signal is not mature [26], the method mainly used are FFT power spectrum analysis, FIR filtering, quantitative analysis, Laplace transform, wavelet transform entropy, support vector machines and MP algorithm, the research results are still not used for clinical diagnosis [27–29].

Due to the difficulty in identifying high-frequency oscillation rhythm, the remainder of this paper is organized as follows. Chapter 2 is the pre-treatment process for epileptic EEG, at first handle the original data with wavelet threshold method and 50 Hz octave notch to eliminate frequency interference signals. Then, according to its own rhythm ripples and FRS frequency characteristics, process the signal which is already noise reduction with FIR digital band-pass filter. Chapter 3 is the feature extraction and lesion location of high-frequency oscillatory rhythm in epileptic EEG signals. The Teager energy operator is first used to calculate the energy of each channel signal, and then combined with the length of the curve of the Teager energy operator to define the threshold and enhance the separation effect. In addition, the Empirical Mode Decomposition (EMD) decomposition is introduced to perform Teager-huang transform on the signal to obtain the time-frequency-energy distribution characteristics of the signal. Finally, a qualitative power spectral density method and a quantitative EMD energy entropy method was used to compare and analyse different leads of epilepsy data to locate epilepsy lesions. The algorithm ideas in this paper are shown in Fig. 1.

2. The acquisition and pre-processing of epilepsy EEG signal for high frequency rhythm

2.1. The acquisition of high-frequency epilepsy EEG oscillation signal

In general, there are two main methods to extract EEG. One is to put the disc electrode on the scalp, which requires that the electrode is connected to the scalp reliably, and the EEG machine is recorded by the electroencephalograph, which is called electroencephalogram (EEG). The other way is by putting the electrode directly into the exposed cerebral cortex surface to record the electrical activity when an animal test or a craniotomy is performed in a clinical case, which is called cortical electroencephalogram (ECOG). Both of them reflect the self-generating activities of cerebral cortex. Because the high frequency oscillatory rhythm signal in epileptic EEG is weak and its frequency is high, it is usually placed on the surface of the cerebral cortex after craniotomy, or the depth electrode is directly placed on the cerebral cortex, and then the high sampling rate is used to collect it.