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Seizure Mapping Using an Intracranial Implantable Ultrasound Device

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***Abstract*— Surgical epilepsy treatment remains a problem that low spatial resolution of about 1cm result to low cure rate of about 30%. The implanted high frequency ultrasound transducer, which can be incorporated with the subdural electrode array, is proposed here in order to provide high resolution 3D seizure mapping using ultrasound to guide the epilepsy surgery. The purpose of this study is to investigate the quantitative ultrasound technique in distinguishing between different blood concentrations, and validate the effectiveness of the technique in phantom experiment and animal experiment. The measured mean scatterer spacing of the 100% anticoagulated bovine blood is about 0.0315 mm.**

Keywords--- seizure mapping; epilepsy surgery; ultrasound transducer; quantitative ultrasound

I. INTRODUCTION

Surgical epilepsy treatment is an option for patients with focal seizures that remain a problem despite other medication treatments [1]. The outcome of epilepsy surgery greatly depends on the accurate localization of epileptogenic focus [2]. In clinical practice, it was achieved by monitoring the Electrocorticography (ECoG) with subdural electrode array. However, the low spatial resolution of about 1cm result to the low cure rate of about 30% [3].

Recent study reported the functional ultrasound (fUS) technology for detecting and mapping the cerebral blood volume (CBV) in brain, which allows the investigation of coupling between neuronal activity and hemodynamic response as seizures evolve [4]. In order to provide high resolution 3D seizure mapping using ultrasound to guide the epilepsy surgery, the implanted high frequency ultrasound transducer which can be incorporated with the subdural electrode array was proposed.

The change in cerebral blood volume (CBV) caused by epilepsy can be defined as the change in the total amount of red blood cells passing through the region during the same period. The microscopic cause of CBV is currently unclear. As far as the author's current knowledge is concerned, there may be several reasons, such as changes in blood flow velocity, changes in blood concentration, changes in diameter of blood vessel, etc. In this study, we hypothesized that changes of cerebral blood volume in the brain is caused by the variations of blood concentration. Based on this hypothesis, the purpose of this study was to develop echo analysis algorithm that can distinguish between different blood concentrations, and validate the effectiveness of the algorithm in phantom experiments and animal experiments.

High frequency ultrasound can be used to characterize the microstructure of tissue non-invasively [5]. The ability to study the ultrasound backscatter from cell pellets offers new opportunities for distinguish between different blood concentrations [6,7]. In this work, cepstral analysis has been used to estimate the mean scatterer spacing from blood with different concentrations. This work contributes to the overall objective to develop distributed high frequency ultrasound transducer array which can be incorporated with the subdural electrode array and provide high resolution 3D seizure mapping to guide the epilepsy surgery.

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II. METHODOLOGY

Quantitative cepstral technique converts the multiplicative operation between the Fourier domain response and the scatterer properties to an additive one. The complex cepstrum is defined as the inverse Fourier transform of the logarithm of the frequency spectrum of the signal:

$$C_c(n) = IFT\{Log\,(X(w))\} \quad (1)$$

After this, the logarithm is applied on the complex quantity X(w). The logarithm of a complex number is defined as:

$$Log\big(X(w)\big) = Log(A) + j\theta \quad (2)$$

This method was tested in phantom experiments to estimate the mean scatterer spacing from the backscattered RF signal. A threshold rule was used to select relatively sharp peaks in the cepstrum plot and to calculate the mean value of the credible peak intervals.

A. Phantom Experiment

As shown in Fig.1, two parallel pipes (OD=1mm, ID=0.6mm) were buried in the phantom model at two different depths. Different concentrations of blood were flowing in the pipes with the flow rate accurately controlled by a precisely controlled syringe pump.

A 20MHz high frequency ultrasound transducer with dimensions of 3x1.5x0.8mm^3 was placed above the parallel pipes. The selection of this frequency was based on Pasternak's work, indicating the ability to observe cell scattering properties [7]. DPR500 dual pulser/receiver (Jsr Ultrasonics, Pittsford, New York) was used to transmit excitation signal to the transducer and amplify the received echoes. The performance of the ultrasonic transducer was measured in echo test using the steel plate, as shown in the Fig.2.

In this experiment, different concentrations of blood, including 100%, 80%, 60%, 40%, 20% and 10%, flow through the pipeline at different flow rates, respectively. The different ultrasonic echo signals were acquired when the blood flow through the pipeline stably. The cepstral technique was used to analyze the echo signals by estimating the mean scatterer spacing of the blood, thereby achieving the goal of distinguishing between different blood concentrations.

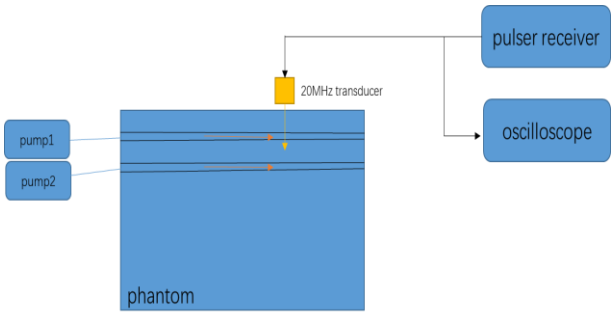

Fig.1. Setup of phantom experiment

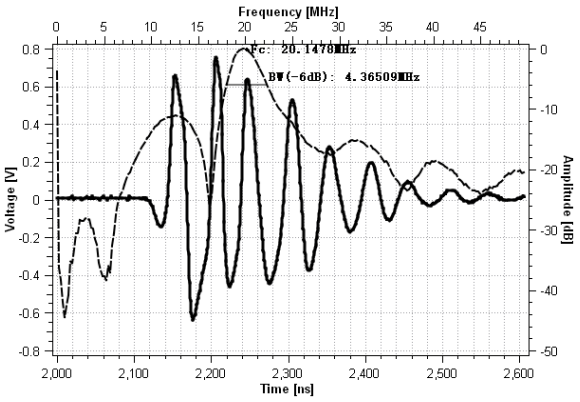

Fig.2. Time and frequency domain of the ultrasound echo generated by the 20MHz single element ultrasound transducer measured in echo test using the steel plate

B. Animal Experiment

The design of the animal experiment simulates the scene of EEG monitoring. The high-frequency single-element ultrasound transducer was used in conjunction with EEG to record the whole episode of epilepsy. In this experiment, the same 20MHz single-element ultrasound was used.

In a rabbit model, electrophysiology signal and ultrasound echoes from the brain were simultaneously recorded in real time (shown in Fig.3). Seizure-like discharges were induced by injecting 4-AP into the cortex, through a glass microelectrode using a Nanoject II injector. A second glass microelectrode filled with saline was positioned <0.5 mm from the 4-AP electrode to record the local field potential (LFP). The LFP was amplified, band-pass filtered and digitalized. The 20MHz high frequency ultrasound transducer was placed close to the 4-AP electrode and on the surface of cortex. Here, in animal experiment, the ceptral analysis was not performed yet

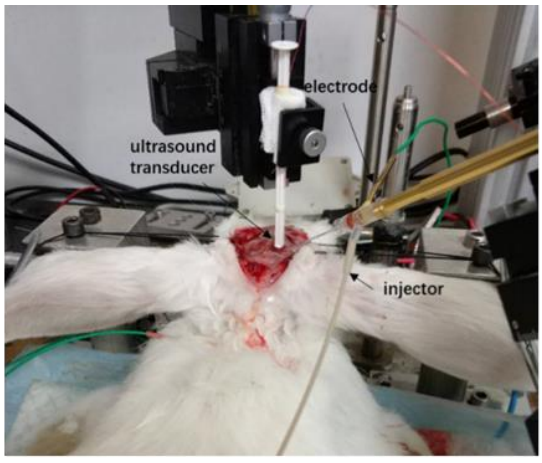

Fig.3. Setup of rabbit epilepsy experiment

III. Results & Discussion

A. Phantom Experiment

In the phantom experiment, different concentrations of blood flow signals were collected to estimate the mean scatterer spacing in order to distinguish blood with different concentrations. The echo signals collected by the single-element ultrasound transducer in the experiment is shown in Fig.4. The front wall signal and the back wall signal, as well as the blood flow signal in the middle, can be clearly seen. The cepstral analysis was performed on the middle blood flow signal to obtain the relationship between the cepstrum value and the distance. The distances between two adjacent peaks were measured by selecting the local peaks, and the obtained distances were averaged to obtain the mean scatterer spacing.

As can be seen from Fig.5, the mean scatterer spacing of the 100% anticoagulated bovine blood is about 0.0315 mm, and that of the 80% anticoagulated bovine blood is about 0.0326 mm. However, it was found that the peaks of the cepstrum are difficult to determine when the concentration of bovine blood is below or equal to 60%. Thus, it becomes difficult to accurately estimate the mean scatterer spacing. It may be because the intensity of the blood flow echo signal is too weak, resulting in a too low SNR ratio.

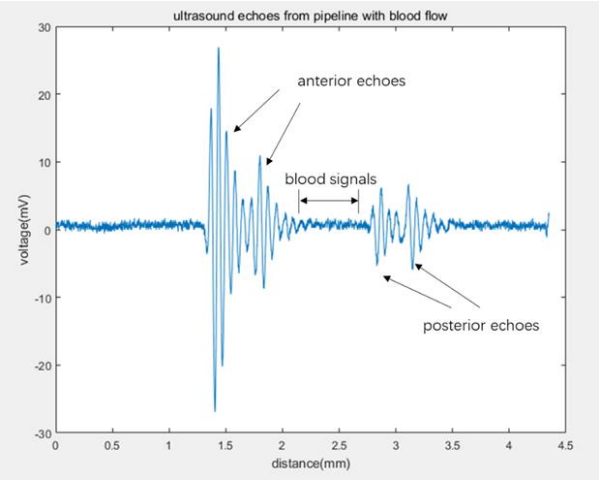

Fig.4. The echo signals received by the transducer in phantom experiment

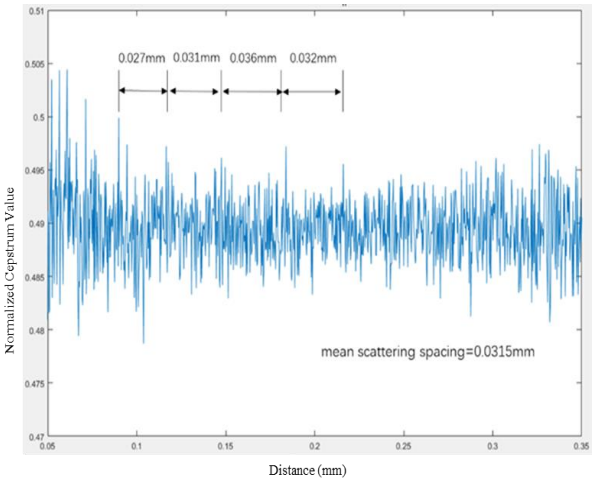

Fig.5. Mean scatterer spacing estimated from the result of 100% anticoagulated bovine blood

B. Animal Experiment

The precise timing of the onset and termination of the seizure was established based on the analysis of LFP. Simultaneously recorded ultrasound signal was then analyzed to see the seizure induced ultrasound variation and find out the location. As shown in Fig.6, the absolute value of pulse-echo voltage at the position about 1.8mm beneath the cortex has substantial change at the onset of seizure. The pulse-echo voltage is reduced by about 25% compared with that at normal state. This can be explained by the corresponding functional hyperemia during the period of seizure, causing the reduced energy of backscattered ultrasound signal. Further analysis is needed to find out how the mean scattering spacing changes at the onset of seizure.

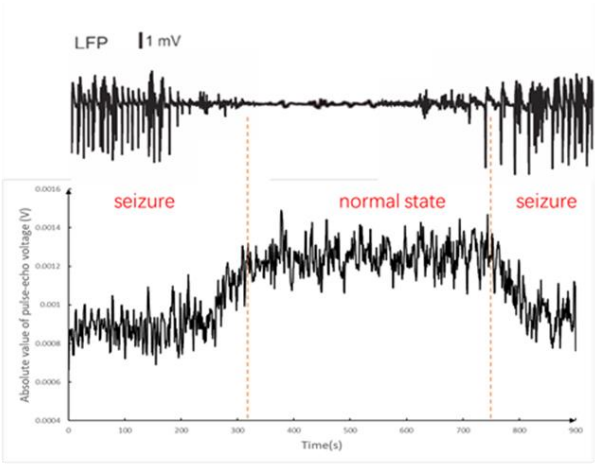

Fig.6. The onset of the seizure shown by the recorded local field potential (LFP) and the corresponding pulse-echo voltage at the position about 1.8mm beneath the cortex

IV. Conclusion and Future Work

In this work, an implanted high frequency ultrasound transducer which can be incorporated with the subdural

electrode array was proposed. Cepstral analysis was performed to distinguish between different blood concentrations by estimating the mean scatterer spacing. The measured mean scatterer spacing of the 100% anticoagulated bovine blood is about 0.0315 mm. Further analysis is needed to find out how the mean scattering spacing changes with different blood concentrations and flow velocities. It will be investigated that how the mean scattering spacing changes at the onset of seizure.

ACKNOWLEDGMENT

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