Monitoring Electric Current in Biological Tissues by Optical Coherence Tomography

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Abstract: The capability of optical coherent tomography (OCT) to detect changes induced by physiological level electric field in biological tissue is demonstrated. The suggested method can potentially image the electro-kinetic properties of tissues with OCT.
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The electric field effects on biological tissue were previously observed using ultrasound [1]. This included repeatable changes in the amplitude and phase of the echo signals that correlated with the duration, strength and direction of the applied electric current. The electro-kinetic phenomenon (EKP) was suggested as a possible underlying mechanism for strain induction in tissue due to the applied electric field [2,3]. Effects of EKP were investigated on cartilage [4] using optical coherence tomography (OCT), because cartilage had larger fixed charge density than other soft tissues and was expected to have larger EKP.

In the present study, we demonstrate the ability of OCT to detect electric-field induced changes in various soft biological tissues such as heart tissue, fat, and muscle. We show that the OCT amplitude data allows for measuring time resolved changes in tissue optical properties at the laser source wavelength of 1310 nm. A low-frequency electric current at the physiological level was passed through *ex-vivo* samples of porcine heart tissue using the scanning galvanometer mirror system (Cambridge, MA) fixed at one position.

To measure changes in the depth-resolved optical reflectance the prototype fiber based swept source OCT (Swept Source Laser Model # SL1325-P16, Thorlabs Inc. Newton, NJ) system was used. This system employed a broadband light source with the central wavelength of 1310 nm and the spectral bandwidth of 100 nm. The signal from the detector was triggered and digitized using a 16-bit 1.25 MHz data acquisition card with a sampling rate of 50 MS/s. Thorlabs Swept-Source Optical Coherence Tomography Microscope software package running on a Windows XP personal computer was used to manage data acquisition and to display images. The synthetic function generator was used as an alternating current (AC) power source (Stanford Research, model DS335). It was connected to the electrodes placed on the opposite surfaces of the tissue sample, which was oriented to allow the electric current to flow along the tissue fibers.

To investigate the ability of OCT to detect the current-induced changes in the tissue optical properties, the 0.1 Hz AC square waves were applied to samples using different amplitudes of the applied voltage. Voltages of 0 to 10 Volts amplitude were applied during 3 minute trials at a rate of 1 frame per second. Each trial preceded by a 2-minute baseline period to check the systems stability due to possible vibrations. Each OCT frame contained 1024 axial measurements of echo time delay (A-scans). The OCT frame size was 3.0 mm × 3.0 mm with 512 × 1024 pixels. The data analysis involved the column-wise signal averaging to yield a single 512 pixel long axial profile for each OCT frame using MATLAB. To evaluate the amplitude of changes in the collected OCT signals, layers were chosen in the axial profiles. Each layer was about 5.86 μm (3 mm/512 pixels) thick. The OCT signal was normalized to the baseline.

Figure 1(a) shows the time course of a typical OCT signal measured from some layer of a porcine heart. The first 120 s were acquired before the AC application. The solid box (interval 120 to 300 s) indicates the time interval during the AC voltage (10 V, 0.1 Hz) application. During the last 180 s the data were also acquired without the voltage.

To eliminate any drift in the signal, such as shown in Fig. 1(a), a temporal de-trending was applied to the signals. Figure 1(b) shows the time course of the de-trended signal.

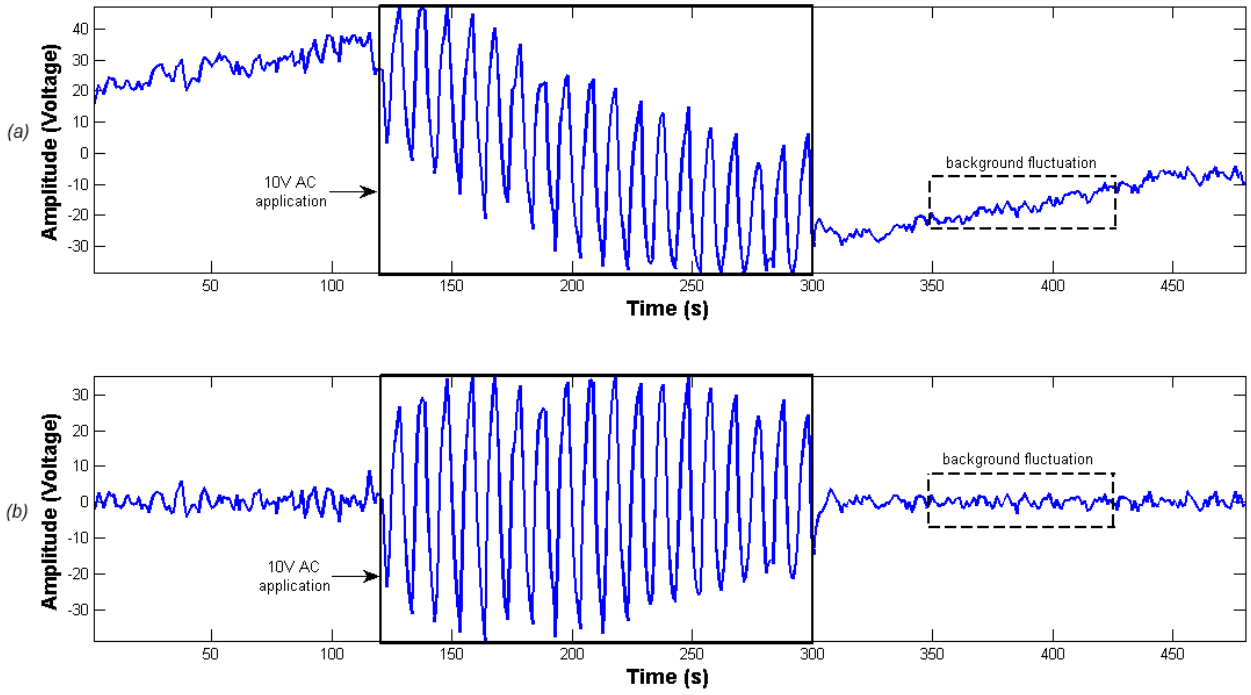

Figure 1. The time course of the OCT signal acquired on a porcine heart sample before, during (in solid square), and after the AC voltage application. (a) A typical raw OCT signal. (b)The same signal after the de-trending

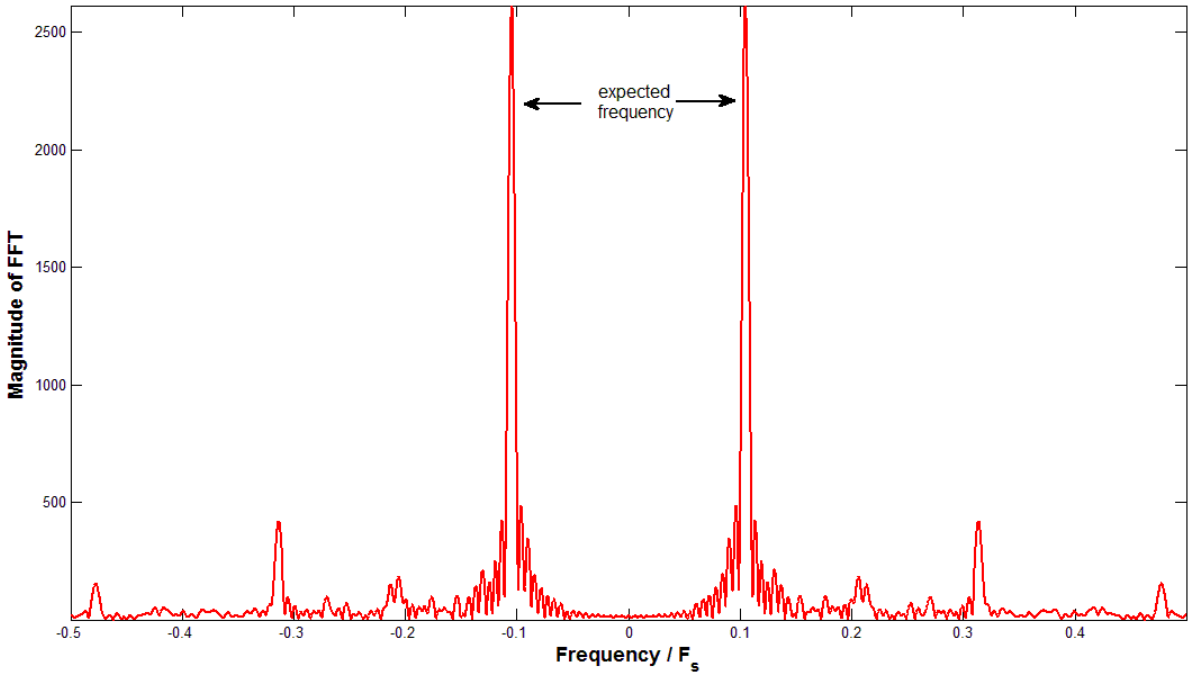

Figure 2. Fourier spectrum of the OCT signal during the AC application obtained with the Fourier transform.

The Fourier spectrum of the de-trended signal during the interval of AC applying was used to calculate the frequency and amplitude of changes in the OCT signal (fig. 2).

The frequency component at 0.1 Hz in Figure 2 and its harmonics were related to the applied square waveform.
To quantify the amplitude of the signal change, a small window was chosen within the Fourier spectrum at the expected AC excitation frequency (between $0.959f_0$ and $1.041f_0$). This method was used to measure electrically induced OCT signal changes at different AC amplitudes and frequencies. Fourier transform was applied to each layer in the OCT signal to measure the Fourier transform magnitude in the presence or absence of an applied electric field.

In Figure 1, a strong and highly localized OCT signal response is observed during AC application, which is well-correlated with the applied voltage. The magnitude and the sign of the signal change correlate with the alternating positive and negative polarities in the applied voltage. No response was observed outside the AC interval region. The signal within the AC interval oscillated at 0.1 Hz, which was the same to the excitation frequency. The spectrum in Figure 2 clearly reveals the frequency (0.1 Hz), magnitude and its harmonics. The spectral peak magnitude is proportional to the excitation voltage. This demonstrates an immediate OCT signal response to the external electric field.
In summary, the experimental results demonstrate the possibility of using OCT for depth-resolved detection and imaging of changes in the optical reflectance of soft biological tissues due to an external electric field. Since these changes are likely related to the EKP, our method potentially can be applied to image the electro-kinetic properties (such as the fixed charge density) of soft tissues.

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