Monitoring Electric Current in Biological Tissues with Optical Coherence Tomography (OCT)

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1. INTRODUCTION

- **Background**
  - In this study, AC or low-frequency electric field at the physiological level (< 2V/cm) were passed through porcine heart tissue while optical coherence tomography (OCT) signals from an OCT system were acquired continuously with the OCT probe fixed at one position.
  - Previous studies have shown morphological changes in tissues due to applied electric fields but the mechanism of these interactions is not fully explained yet.
  - OCT provides a novel technique to measure the induced changes in tissues caused by an applied electric field.

- **Hypothesis**
  - The effect of an externally applied electric field to the biological tissue can be detected using OCT signals.

- **Objectives**
  - Use OCT signals scattered from heart tissue as a probe to provide a new method to measure induced changes caused by an applied electric field.
  - Quantify the OCT signals and determine if the amplitude of OCT signals show repeatable changes correlated with the duration, frequency, and magnitude of the applied electric current.

2. MATERIALS AND METHODS

- **Introduction**
  - A low-frequency electric field at the physiological level was passed through samples of porcine heart tissue *in vitro* while OCT signals using A-mode imaging were acquired continuously with the OCT imaging probe fixed at one position.

- **Experimental Setup**
  - A Thorlabs Swept-Source OCT system (Fig. 1) and Thorlabs imaging software running on a Windows XP computer were used to manage data acquisition.
  - A typical experiment setup (Fig. 2) involved electrodes embedded into opposite ends of a porcine heart specimen and placed on a non-conductive platform
  - A function generator produced a low frequency (0.1 Hz, 0.5 Hz, or 1.0 Hz) square wave signal combined with a low peak-to-peak amplitude (10-V, 5-V, and 3-V).

Figure 1: Thorlabs Swept-Source optical coherence tomography imaging system

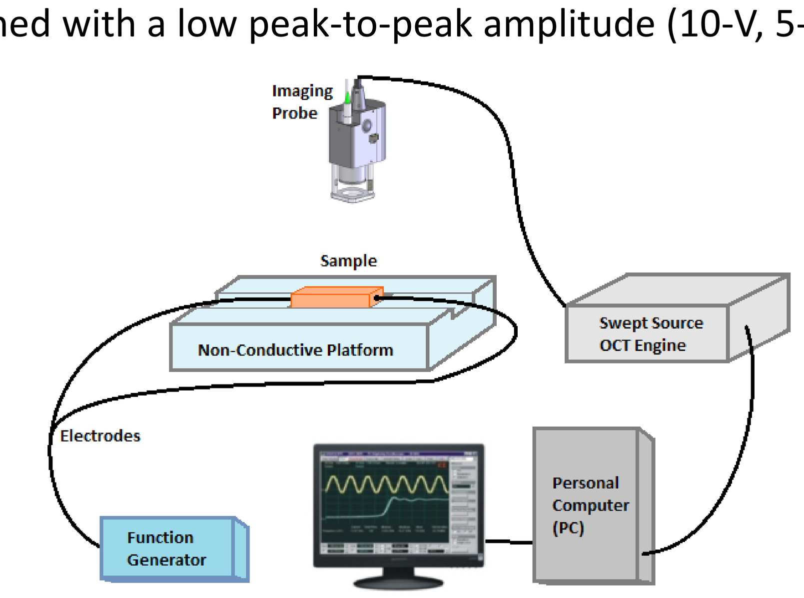

Figure 2: Diagram of experiment setup.

- **Experimental Protocol**
  1. Before electric current was applied, OCT frames containing signal information were acquired for a time interval to serve as a baseline to check the system stability.
  2. Next, an AC voltage source was applied to the sample to obtain OCT signals containing the amplitude changes.
  3. Finally, the sample was disconnected from the voltage source to acquire OCT signals after electric current application.

- **Data Processing & Analysis**
  - MATLAB was used to process and analyze the OCT data in this study.
  - Each original frame obtained was averaged into a single A-line and represents the depth (1.5 mm) of the sample at a single location.
  - All the averaged OCT frames were plotted on a gray scaled map (Fig. 3) or an amplitude shifted color map (Fig. 4).
  - To quantify the amplitude change of collected OCT signals, windows were chosen in the A-mode signal and plotted versus frame number (Fig. 5).
  - Approximate spectrum was obtained with Fast Fourier Transform (FFT) to determine if frequency in the OCT signal corresponds to the frequency applied by the function generator (Fig. 6).

3. RESULTS

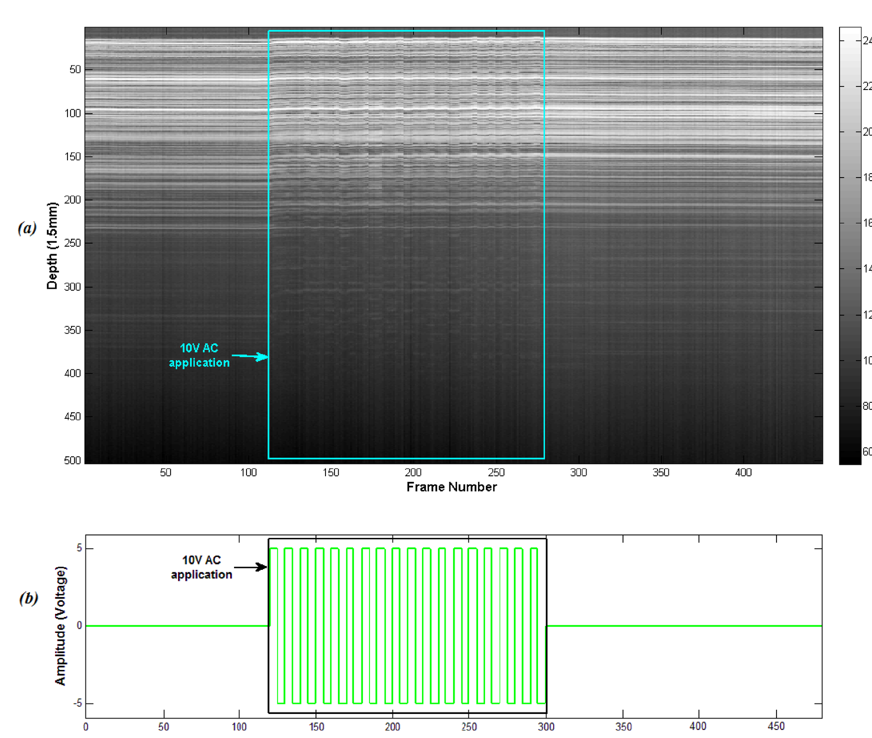

Figure 3: Comparison between the applied AC square-wave signal with the scaled OCT frame data demonstrates the correlation between OCT frame data with the applied voltage.

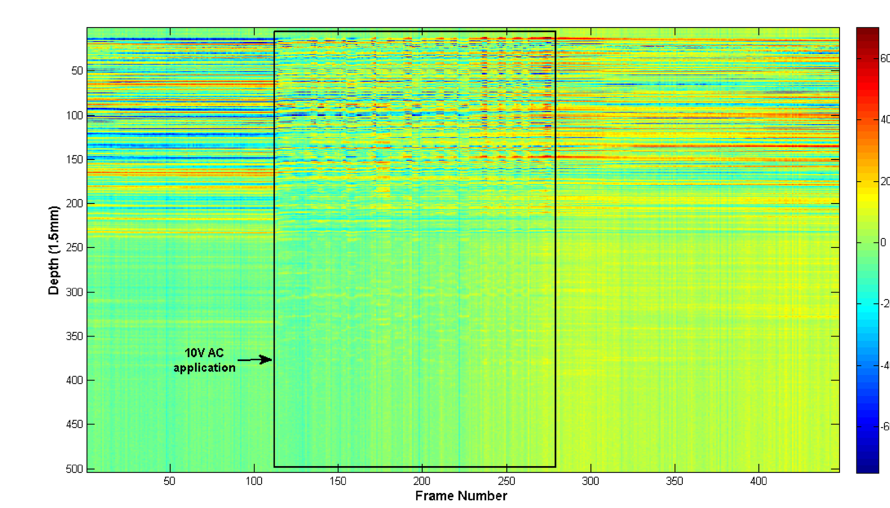

Figure 4: Amplitude shifted color map image of scaled OCT frame data acquired from a piece of porcine heart tissue before, during (solid rectangle), and after electric current application. Each plotted frame (column) is the average of all A-lines contained in the original OCT frame and represents the depth (1.5 mm) of the sample at a single location.

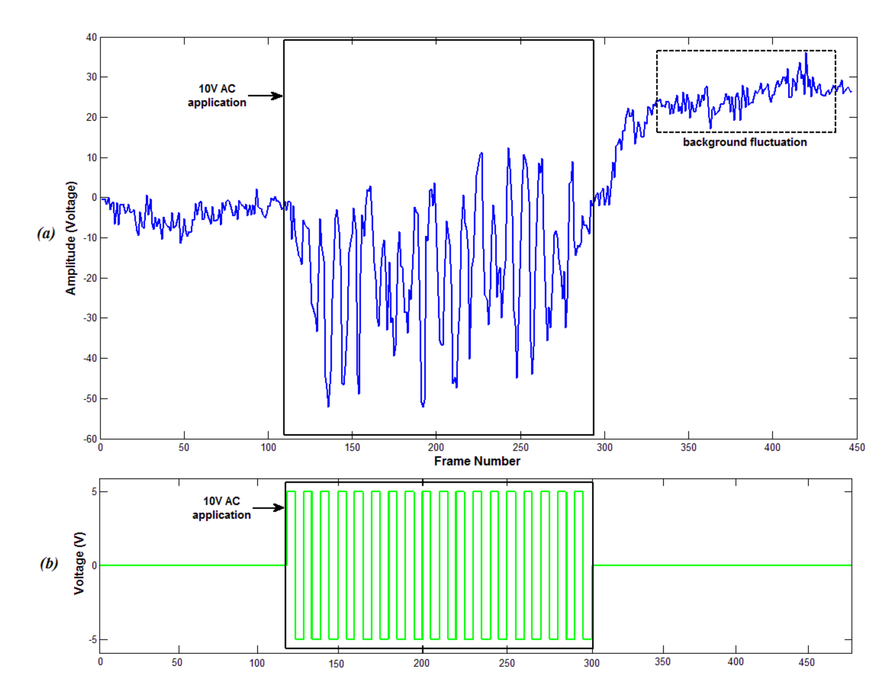

Figure 5: Comparison between the applied AC square-wave signal with the scaled OCT frame data demonstrates the correlation between OCT frame data with the applied voltage and frequency.

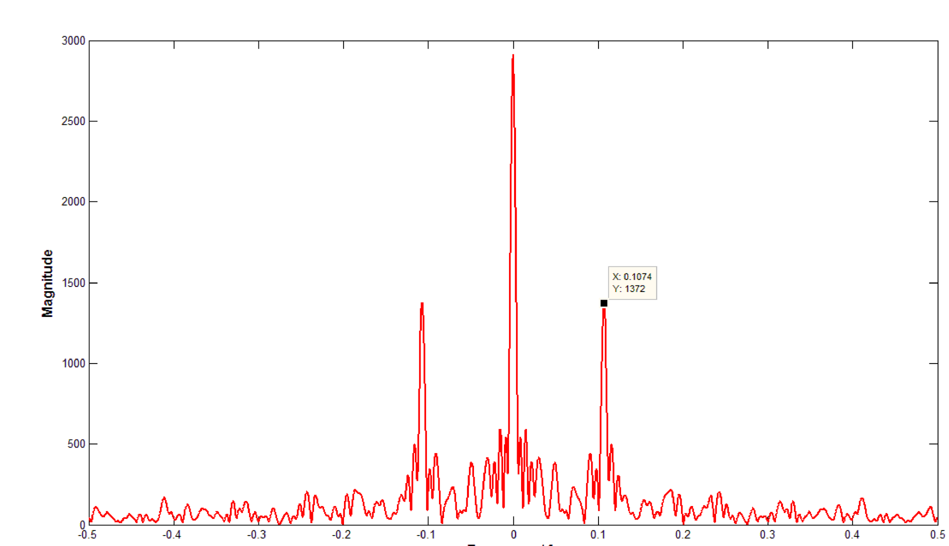

Figure 6: Approximate spectrum of the OCT signal during electric current application with the Fast Fourier Transform (FFT).

Variable	Value				
Applied Voltage (V)	10-V	5-V	3-V	10-V	10-V
Applied Frequency (Hz)	0.1 Hz	0.1 Hz	0.1 Hz	0.5 Hz	1.0 Hz
Frames per second (fps)	0.93 fps	0.92 fps	0.92 fps	1.76 fps	1.76 fps
Magnitude of Change in OCT signal (Arbitrary Unit)	1372	660	539	275	142
Frequency (Hz) of OCT wave	0.1000 Hz	0.0998 Hz	0.0998 Hz	0.5014 Hz	0.7520 Hz

Table 1: Summary of results for applied low-voltages (10-V, 5-V and 3-V) combined with low-frequencies (0.1 Hz, 0.5 Hz and 1.0 Hz).

4. DISCUSSION

- **Discussion of Results**
  - Fluctuations, intensity shifting, and cycles appear during interval of applied electric current (Fig. 3 and Fig. 4) when comparing the frames inside the rectangle (Applied AC) to the frames outside (No AC).
  - A window of the OCT signal from the OCT frame data is plotted (Fig. 5) to investigate amplitude change due to an induced electric field.
  - Upon the electric current application, a sharp increase in amplitude and distinct cycles between periods are shown.
  - This suggests that the amplitude change induced by the current application is sensitive to the frequency and voltage of the applied AC signal and the amplitude change is reversible.
  - Therefore, some changes in the properties of the biological tissues are responsible for the amplitude change in the OCT signal.
  - Fast Fourier Transform (FFT) was applied to the OCT signal to confirm the frequency of the OCT signal during electric current induction (Fig. 6)

- **Limitations**
  - OCT imaging is highly sensitive to random background mechanical motion of the table and traffic in and near the laboratory.
  - Data acquisition requires a responsive computer workstation and adequate hard drive space.

5. CONCLUSION & FUTURE WORK

- **Conclusion**
  - It has been observed that the amplitude of the OCT signals show repeatable changes correlated with the duration, frequency, and magnitude of the applied voltage in heart tissues.

- **Future Directions**
  - Numerous questions can potentially be answered with the help of OCT.
  - The technique developed in this thesis can result in a valuable tool for investigating morphological and mechanical responses of biological tissues to low-intensity and low-frequency electric fields.
  - Further measurements on different samples need to be done to gather more quantitative information to help answer these questions and to understand the underlying mechanisms that induce changes in biological tissues during electric current application.
  - The electrokinetic effects may contribute to the underlying mechanisms.

6. REFERENCES

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7. ACKNOWLEDGEMENTS

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