

Broadband Dielectric Properties of Adrenal Gland for Accurate Anatomical Modelling in Medical Applications

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Abstract – Dielectric properties of biological tissue are important in safety assessment and evaluation of novel medical imaging and therapeutic devices. This paper reports frequency dependent dielectric properties of adrenal tissue, which is a potential target for microwave ablative therapy to treat benign and malignant adrenal tumors. Dielectric properties of bovine adrenal glands were measured using open-ended coaxial probe over 0.5 to 20 GHz, and a two pole Cole-Cole model was fitted to the measured data. The parameters of Cole-Cole model are presented in this paper.

1 INTRODUCTION

The dielectric properties of biological tissue are important in modelling and evaluating the energy deposition in a body exposed to radio waves. There has been a number of studies reporting dielectric properties of various animal and human tissue over a wide frequency range of 10 Hz to 100 GHz [1-10]. Although dielectric data of most of the body tissues are available in the literature, there are some tissues that have received little attention due to lack of demanding applications. With increasing interest in electromagnetic therapeutic interventions, accurate knowledge of dielectric properties of these body tissues has become important. In recent years, several radio-wave medical imaging and therapeutic systems have been developed, with radio-wave ablation being one of the most notable development to treat cancerous lesions in the human body. Radio-wave thermal ablation has been investigated for minimally invasive treatment of adrenal adenomas [11-12]. The development of ablative therapy for adrenal adenomas require accurate knowledge of dielectric properties of the adrenal gland. However, there is very limited data available on the dielectric properties of the adrenal gland. To best of our knowledge, there is only one study [13] to date in literature where the dielectric properties of outer layer of the porcine adrenal gland (cortex) were measured. Based on the anatomy of adrenal gland, there are two distinct tissue layers in the gland, referred as adrenal cortex, and medulla. Therefore, it is necessary to measure the dielectric properties of both tissue layers for anatomically accurate modelling of the adrenal gland.

This paper presents parameters of two pole Cole-Cole models fitted to the measured dielectric properties of cortex and medulla of bovine adrenal gland. The remainder of this paper is organized as follows: Section 2 details the materials, measurement method and uncertainty, and the Cole-Cole model. Measured data and the parameters of Cole-Cole model

are presented in section 3, while the conclusions are presented in section 4.

2 MATERIALS AND METHODS

2.1 Tissue Samples

The bovine adrenal samples (n=12) were obtained from a local abattoir, within 2 hours post mortem. The samples were kept inside the peri-adrenal fat and removed at the time of measurements to avoid excessive dehydration. The temperature of the glands at the time of measurement was recorded at each site of measurement and found in the range of normal room temperature ($22^{\circ}\text{C}\pm 0.8$). The interior of the adrenal gland was accessed through a cross sectional cut, and measurements were performed on internal surface of the tissue to minimize the effect of surface dehydration [14]. Fig. 1 shows one of the adrenal gland samples and the measurement sites on the cortical and medullary tissues.

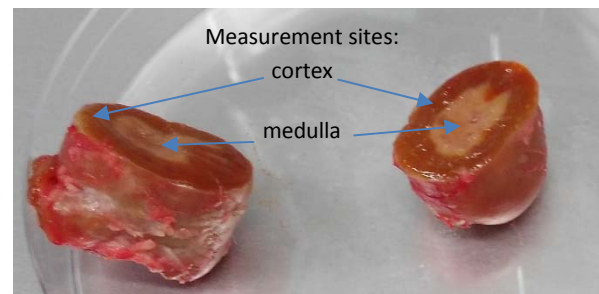


Figure 1: Cross sectional photograph of the adrenal gland, showing cortex and medulla.

2.2 Dielectric Measurements

Measurements were performed using a slim-form dielectric probe (Keysight 85070E, Santa Rosa, CA, USA) connected to a vector network analyzer (Keysight E8362B), and reflection coefficient (S11) was recorded at 101 linearly spaced discrete frequency points over 0.5 to 20 GHz. The S11 parameters were converted to complex permittivity using Keysight material measurement software suite (Keysight N1500A). The tissue sample was pressed against the probe using a lab jack to achieve good contact for measurements. The samples were kept inside the peri-adrenal fat in a sealed bag, and removed at the time of measurements. Interior of the gland was exposed with a cross sectional cut to perform three measurements on

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each tissue (adrenal cortex and medulla). Total of 36 broadband measurements were performed on 12 adrenal glands for each tissue type (cortex and medulla).

2.3 Measurement Uncertainty

Accuracy of the measurement system was evaluated on 0.1M NaCl solution (Honeywell chemicals, Fluka 35275), using the standard analysis technique described in [15]. Total uncertainty of the measurement system was estimated by repeated measurements to assess random and systematic errors. The error was calculated for each discrete frequency point in the measurement and averaged over the measurement frequency band. Table 1 lists the random and systematic errors in the system, assessed over 0.1M NaCl solution at 22°C. The accuracy of the measurement system was calculated as deviation from the reference data obtained from the Cole-Cole model presented in Peyman *et al.* [16].

Uncertainty	Dielectric constant (%)	Conductivity (%)
Repeatability	0.31	0.75
Accuracy	0.65	1.57
Drift	0.03	0.06
Combined uncertainty	0.72	1.74

Table 1: Measurement uncertainty of the system evaluated on standard liquid (0.1M NaCl solution).

Fig. 2 shows a comparison of the dielectric properties of 0.1M NaCl solution measured in this study and the reference data obtained from Cole-Cole model in [16]. Measured data is found to be in agreement with the reference data with average error less than 2%.

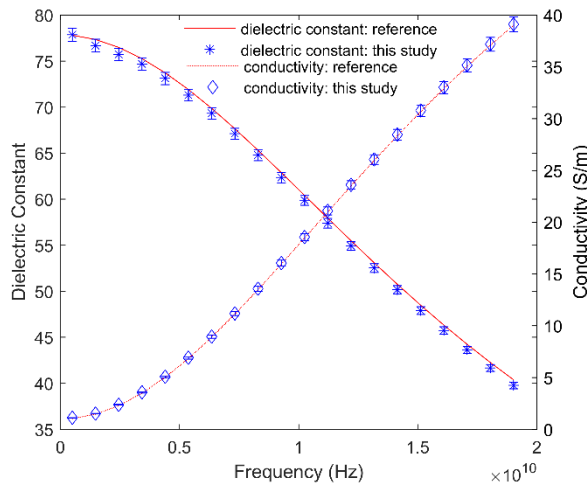


Figure 2: Comparison of measured dielectric properties of 0.1M NaCl solution with reference [16].

2.4 Cole-Cole Model

The broadband dielectric properties are generally expressed in the form of a parametric model. Cole-Cole model is commonly used to represent the frequency dependent permittivity of biological tissues. In the Cole-Cole mode, the frequency dependent complex permittivity is represented as:

$$\varepsilon(\omega) = \varepsilon_{\infty} + \sum_{n=1}^N \frac{\Delta\varepsilon_n}{1 + (j\omega\tau_n)^{1-\alpha_n}} + \frac{\sigma_s}{j\omega\varepsilon_0}$$

Where ε_{∞} is the permittivity at highest frequency; $\Delta\varepsilon_n$ is the magnitude of n^{th} relaxation; ω is angular frequency in radians per second; τ_n is relaxation time of n^{th} relaxation; α_n is an empirical parameter that accounts for broadening of n^{th} relaxation; σ_s is static conductivity; and ε_0 is absolute permittivity.

3 RESULTS AND DISCUSSION

The frequency dependent permittivity of the adrenal tissues was measured on the interior of freshly sliced gland. Fig. 3 shows the measured dielectric constant (Fig. 3-A) and effective conductivity (Fig. 3-B) of the adrenal cortex and medulla. To produce a less cluttered plot, only 21 evenly spaced frequency points are shown on the Fig. 3. For a comparison, the dielectric properties of adrenal gland (cortex) of a porcine from Peyman *et al.* [13] are also shown on the Fig. 3. The effective conductivity of cortex measured in this study closely aligns with [13]; however, a relatively large difference is found in the dielectric constant of the cortex on high frequencies. Since the dielectric constant of cortex and medulla measured in this study follows similar frequency dependent behavior, the difference between the dielectric constant in this study and Peyman *et al.* [13] on high frequencies may be associated to the fitting error.

The measured dielectric data was fitted to a two pole Cole-Cole model, and the parameters of the model are listed in Table 2. A weighted nonlinear least square method was used to fit the data with a fitting error threshold of 10^{-4} .

Parameter	Adrenal Cortex	Adrenal Medulla
ε_{∞}	3.57	3.88
$\Delta\varepsilon_1$	47.08	52.95
τ_1	8.33 ps	7.01 ps
α_1	0.16	0.17
$\Delta\varepsilon_2$	52.31	62.05
τ_2	1.69 ns	4.28 ns
α_2	0.03	0.14
σ_s	0.46	0.62

Table 2: Parameters of the two pole Cole-Cole model fitted to the measured data of Adrenal tissues.

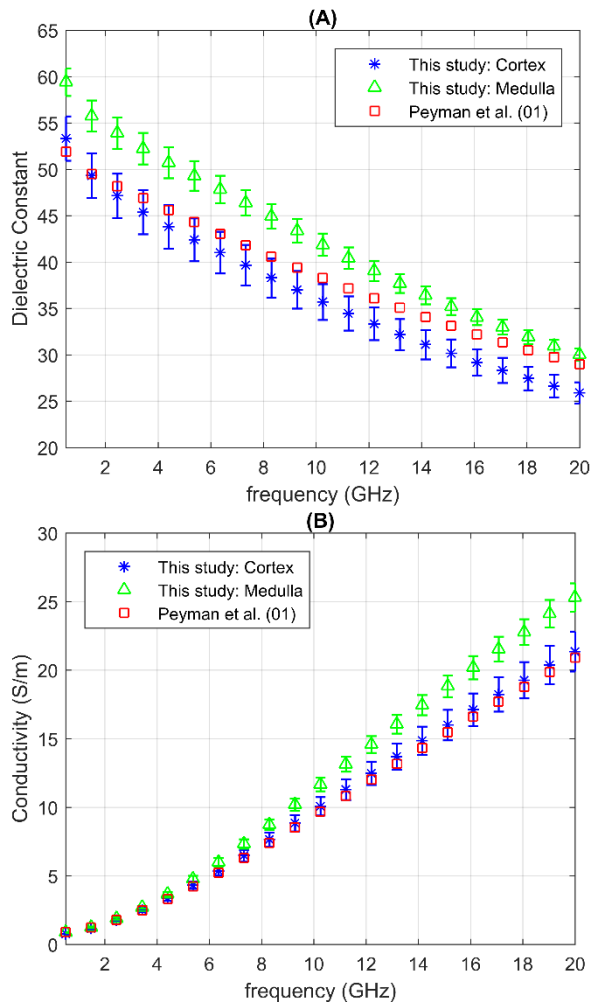


Figure 3: Measured dielectric constant (A) and conductivity (B) of adrenal tissues: a comparison with existing data [13]. Error bars show standard deviation of the measured data.

4 CONCLUSIONS

The dielectric properties of adrenal gland were measured over frequency range of 0.5 to 20 GHz. A two pole Cole-Cole model was fitted to the measured data, and parameters of the model are reported in this paper. The dielectric data presented in this paper can be used to produce anatomical accurate models for evaluation of novel medical imaging and therapeutic devices, particularly in development of microwave ablative therapy for adrenal tumors.

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