Dielectric Spectroscopy Applied to Porcine Tissues

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Abstract - *This paper discusses the characteristics of the dielectric properties: permittivity (ε), conductivity (σ) and dielectric loss (ε") of a porcine tissue. The main objective is to measure and identify the dielectric properties of a porcine lung tissue and porcine cardiac muscle tissue in the frequency range of 20Hz – 20MHz. The sample of the lung tissue (0.88 mm2) was extracted from a pig fetus and the cardiac muscle tissue (2.10 mm2) from an adult pig. The previously preserved and vacuum sealed organs were stored at 15°C. Afterward, the sample tissues were placed in individual bags and stored in a portable cooler until the electrical parameters were measured. The dielectric properties were calculated and measured by the Impedance Analyzer E4990A and the Dielectric Material Test Fixture model 16451B. Both tissues properties were analyzed. The results agreed with the literature.*

INTRODUCTION

The electrical properties of biological tissues have been of interest for over a century. The application field for complex electrical impedance spectrometry is still today an area of active research. This properties determine the pathways of current flow through the body and, thus, are very important in the analysis of a wide range of biomedical applications and medicine such as the diagnosis of cancerous tissues. On a more fundamental level, knowledge of these electrical properties can lead to an understanding of the underlying basic biological processes. To analyze the response of a tissue to electric stimulation, we need data on the specific conductivities and relative permittivity of the tissues or organs. A microscopic description of the response is complicated by the variety of cell shapes and their distribution inside the tissue as well as the different properties of the extracellular media. Therefore, a macroscopic approach is most often used to characterize field distributions in biological systems. Moreover, even on a macroscopic level, the electrical properties are complicated. They can depend on the tissue orientation relative to the applied field, the frequency of the applied field, or they can be time and space dependent [1-2].

1.1 Electrical properties of biological tissues

Electrical impedance is the opposition that a biological tissue presents to the passage of a current through it [3]. The characterization of healthy and pathological tissues, based on their electrical properties in a given frequency spectrum, is called Electrical Impedance Spectroscopy (EIE) and this is possible since the cells have attributes that make them equivalent to an electrical circuit that has elements such as resistance, capacitors and inductors that oppose the passage of alternating current, where the cell membrane acts as a capacitor in its extracellular part as a resistance in its intracellular portion together with the ionic channels [4]. Biological tissues have properties of electrical conductivity (σ) and permittivity (ε); being tensor properties of the tissues. The conductivity and permeability of biological tissues are found as a function of frequency. These frequencies may vary as a collection of membranes that separate intracellular and extracellular spaces [5]. The electric properties of tissues are therefore themselves a direct consequence of the composition and structure of those tissues. In biological tissues, the electric current influences the component parts that have a net electric charge and / or a dipolar electric moment. The carries of charges are mainly ions and the most important source of dipolar moments lies in the polar molecules of tissue water, and in the protein and lipid structures that make up the membranes or cell interfaces. The movement of these charges induces a conduction phenomenon in the material, and the polarization of the various dipoles results in a dielectric relaxation phenomenon [6], as shown in figure 1.

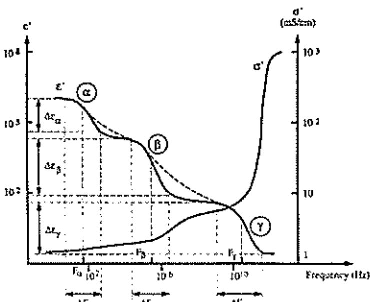

Figure 1 - Conductivity and permittivity in function of the frequency.

1.2 Porcine Tissues

In medical research, animal models are widely used to develop new technologies and cure various diseases. Although different animals are used for different studies, porcine tissue gives similar biological responses to humans, and medical applications evaluated within porcine tissues can provide a better understanding of the interaction with human tissues. The goal of this study is to identify dielectric properties of porcine tissues [7].

2. Materials and Methods

To carry out the study of dielectric spectroscopy applied to biological tissues, 2 samples of porcine tissues were obtained; one of these samples belonged to adult pig tissue with 4 days after death and the other tissue sample belonged to the pig fetus, preserved in formalin with unknown dead days. In Table 1, we can see the thickness and area of the porcine tissue samples.

Tissue Type	Area	Thickness
Fetal pig lung	0.88 mm^2	0.3 mm
Adult pig myocardium	2.10 mm^2	0.3 mm

Table 1 - Conductivity and permittivity in function of the frequency.

(A) (B)

Figure 2 - (A) Porcine lung tissue of a fetus (B) Adult porcine myocardium tissue.

The cardiac muscle belonging to adult pig and the lung belonging to a pig fetus, for preservation, were cleaned and placed in individual containers with saline solution (0.9% NaCl in H_2O and pH = 6.10), vacuum sealed and stored in a refrigerator whose temperature was approximately 15 °C. Subsequently, on the day of the conductivity, permittivity and dielectric loss measurements, the tissue samples were cut and placed, in small individual bags, and transferred in a portable ice cooler until the electrical parameters were measured. A dissection kit was used, which was sterilized with 70% alcohol, to obtain a symmetrical cut in the tissues.

The conductivity, permittivity and dielectric loss parameters were measured with E4990A Impedance Analyzer in conjunction with 16451B Dielectric Test Fixture. This equipment works at a frequency range of 20 Hz to 20 MHz; allowing to study how the chemical properties of porcine tissues interact with voltages and currents. In this way we were able to monitor and measure the dielectric properties of the tissues. Before using this equipment, it was verified if its calibration was in force. The acquisition of tissue data was performed automatically using software called E4990A material measurement software ®. In order to perform the data analysis and generate the graphics, the Microsoft Excel program was used.

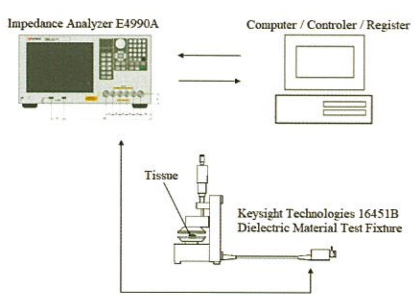

Figure 3 - Diagram of the measurement system used.

The Impedance Analyzer used the following equations to calculate the conductivity (eq. 1), permittivity (eq. 2) and loss factor (eq.3),

$$\sigma = \frac{G\varepsilon_0}{k} \quad \text{(Eq. 1)}$$

$$\varepsilon = \varepsilon' - j\varepsilon \quad \text{(Eq. 2)}$$

$$\varepsilon'' = K\tan\delta \quad \text{(Eq. 3)}$$

Where,

From equation 1 : σ represent conductivity, k is capacitance in the air, ε_0 is permittivity of free space, G is conductance. From equation 2: ε is the relative complex permittivity, ε' is the real part (dielectric constant) which denotes the electric energy storage capacity and ε'' is the imaginary part. From equation 3: ε'' is the loss factor and K is the dielectric constant.

3. Results

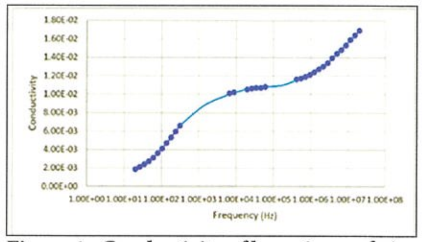

Figure 4 - Conductivity of lung tissue of pig Fetus

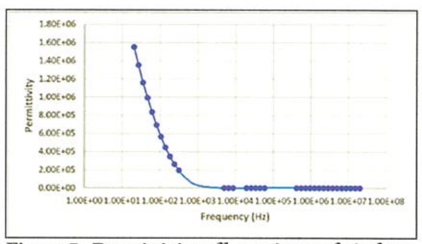

Figure 5 - Permittivity of lung tissue of pig fetus

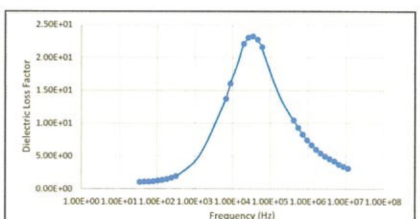

Figure 6 - Dielectric Loss Factor of lung tissue of pig fetus

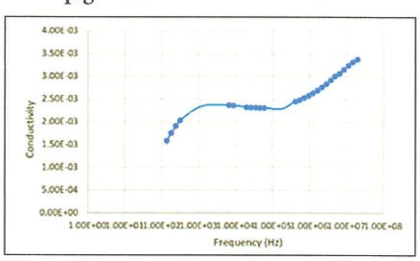

Figure 7 - Conductivity of myocardium tissue of adult pig

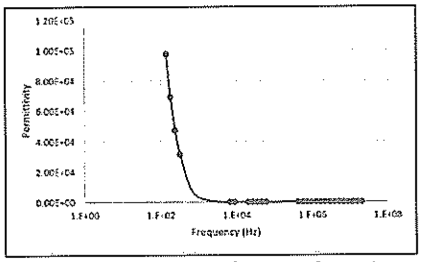

Figure 8 - Permittivity of myocardium tissue of an adult pig

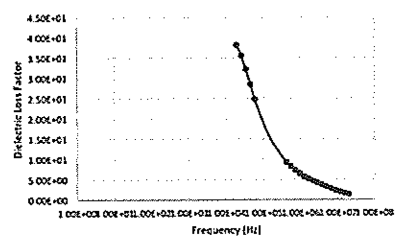

Figure 9 - Dielectric Loss Factor of myocardium tissue of an adult pig

4. Discussion

The software used with the equipment, the E4990A impedance analyzer, integrates the equations of the electrical parameters of the tissues to be able to calculate the conductivity, the permittivity and the dielectric loss factor of the tissues. With this data, these parameters could be plotted in frequency fusion. The frequencies used to evaluate these parameters were 20 to 20MHz. In the graphs of conductivity and permittivity of the fetal tissue of the pig, the alpha, beta and gamma dispersion factors can be clearly observed. The conductivity of the lung tissue (Figure 4) of the pig fetus shows a higher elevation in the beta dispersion factor, compared to the ideal values in a healthy tissue (Figure 1). Likewise, the permittivity of the lung tissue (Figure 5) of the porcine fetus shows a decrease in elevation in the beta dispersion factor compared to the ideal values in a healthy tissue (Figure 1). Therefore, the factor of dielectric loss in the tissues (Figure 6) presents what could be a dependency behavior of an anisotropic structure; since it has a peak in the frequencies 102 to 106. It can be deduced that the electrical properties of the fetal tissue samples have a behavior referred to one that could have suffered some blow or anomaly. Tissues that present an abnormality tend to have changes in the content of cellular water and electrolytes in the properties of the cell membrane, causing changes in the electrical properties of the tissues studied. In order to determine the condition of the tissue, a histological study of the tissue must be performed. On the other hand, the conductivity of the myocardium tissue (Figure 7) of the adult pig shows a normal behavior in the beta dispersion factor, compared to the ideal values in a healthy tissue (Figure 1). Contrarily, the permittivity of the myocardium tissue (Figure 8) of the adult pig shows a fast decrease in elevation in the beta dispersion factor compared to the ideal values in a healthy tissue (Figure 1). Nevertheless, the factor of dielectric loss in the tissues (Figure 9) presents what could be perceived a normal behavior.

5. Conclusion

In this study, the dielectric properties of pig tissue were measured between 20Hz to 20MHz. The results obtained were compared in the literature and show expected behaviors. In the graphs of conductivity, permittivity and loss factor the dispersion factors were clearly observed. The dielectric properties can be used to predict abnormal pathologies tissues, considering that this properties can change with the conditions of life as well as with the state of health of the animal investigated.

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References

[1] D. Miklavic; N. Pavselj, " *Electric Properties of Tissues*", 2006.

[2] Fariñas-Coronado, Z. Paz, G.J. Orta, E. Rodriguez-Denis, "Estudio del factor de disipación dieléctrica como herramienta diagnóstica." P. 250-252, 2002.

[3] Y. Salazar Munosz, Introduccion a la medida de impedancia electrica de los tejidos biologicos, pp. 31-45.

[4] C. Cedillo-Alvarez, G. Villanueva-López and J. Silva-Escobedo, Evaluación De Mediciones De Espectroscopía De Bioimpedancia En Tumores, Mexico, 2017.

[5] Franco Simini · Pedro Bertemes-Filho, "Electrical Impedance Spectroscopy and Basic Electrical Impedance Tomography," in Bioimpedance in Biomedical Applications and Research, Switzerland, Springer, 2018, pp. 22-31.

[6] J. R. Bourne, "Electrical Properties of Biological Tissues," in *Biomedical Engineering*, 1996, pp. 257-266.

[7] T. Karacolak; R. Cooper; E. Selcuk; E. Topsakal, "*Dielectric Properties of Porcine Skin Tissue and In Vivo Testing of Implantable Antennas Using Pigs as Model Animals*", 2013.