Dielectric characterization of permittivity, conductivity and loss factors of porcine tissues by impedance spectroscopy

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Abstract

This investigation was performed to determine whether the mean of fetal porcine tissues analyzed by impedance spectroscopy for their properties adhered to the idealized plots. The statistical process was with the purpose of finding a correlation that established the values as normal and true. For this study 2 samples of 3 types of tissues were obtained, a bone, muscle, and skin sample. All samples belonged to a pig fetus, preserved in formaldehyde an unknown number of days. The parameters were measured with an Impedance Analyzer with a Dielectric Test Fixture at a frequency range of 20 Hz to 20 MHz. In total, 5 tests were performed per sample per tissue. To comply with the statistical approach taken for this investigation, the standard of these 5 tests was calculated for each of them. Higher beta elevations were observed in all conductivity plots along with a sharp decrease affecting beta in all the permittivities. It's proposed that this is just the normal electrical behavior of fetus samples. Though similar, these fetus tissue samples did not adhere to the idealized plots they were meant to follow, which meant the hypothesis was not supported.

Introduction

The flow of charges across the cell membrane is what generates electrical currents. When a cell is stimulated, it allows positive charges to enter the cell through open ion channels. The inside of the cell then becomes more positively charged, which triggers further electrical currents that can turn into electrical pulses. Our bodies use certain patterns of action potentials to initiate the correct movements, thoughts, and behaviors.

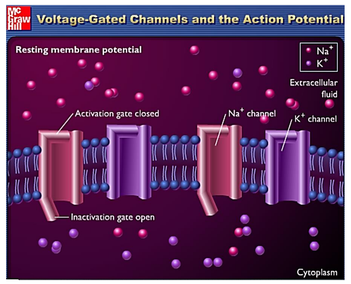

Figure 1: Action potential visual representation

Ideally, we could explain the behavior of biologic tissues analyzed by anything, including electrical impedance spectroscopy. But to analyze the response of a tissue to electric stimulation, data on the specific conductivities and relative permittivity of the tissues is needed. These 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. This investigation will allow to discern and determine the proper characterization of biologic tissue by finding the mean of various samples of porcine tissues and compare them to the idealized plots of the property analyzed.

Objectives

- Characterize, measure and identify the dielectric properties permittivity (ε), conductivity (σ) and dielectric loss (ε") of fetal porcine tissue in the frequency range of 20Hz – 20MHz.
- To find the mean of a correlation that confirms the values determined as accurate can be found and determines they are normal when compared to the idealized plots of the properties analyzed.

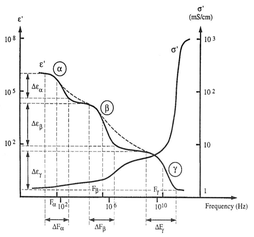

Figure 2: Idealized plot of permittivity and conductivity

Methodology

1. Dissection → 2. Samples acquisition → 3. Storage → 4. Testing → 5. Analyzing → 6. Compiling → 7. Results → 8. Averages

1. Dissection was realized on a pig fetus 'leg', preserved in formaldehyde an unknown number of days.
2. 6 samples acquired: 2 bone, 2 muscle and 2 skin.
3. Saline solution: 0.9% NaCl (pH= 6.10 in H2O).
4. Measured with: E4990A Impedance Analyzer with 16451B Dielectric Test Fixture (20 Hz to 20 MHz).

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

$$\varepsilon = \varepsilon' - j\varepsilon \qquad \textbf{Equation 1}$$

$$\sigma = G\varepsilon_0 k \qquad \textbf{Equation 2}$$

$$\varepsilon'' = K\tan\delta \qquad \textbf{Equation 3}$$

5. Used to analyze: E4990A material measurement software.
6. Data analysis and generating graphics: Microsoft Excel program.
7. Untrue and negative values were removed from graphics, generate results.
8. As 5 test were performed per sample per tissue, the average was found.

Figure 3: Samples used for testing

Table 1: Sample properties

Tissue sample	Properties			
	Length	Width	Thickness	Area
Bone 1	17.2085	4.8768	2.2047	1.3310
Bone 2	16.5862	4.0386	3.5839	1.7907
Muscle 1	16.0782	8.8773	4.3459	4.7727
Muscle 2	16.0528	9.2456	3.8125	4.3586
Skin 1	17.8816	15.1003	0.9449	10.6299
Skin 2	17.9197	13.3858	1.0439	9.4437

Figure 4: Impedance Analyzer & Dielectric test fixture

Results

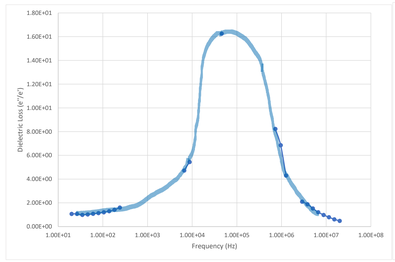

Figure 5: Bone Dielectric Loss Mean

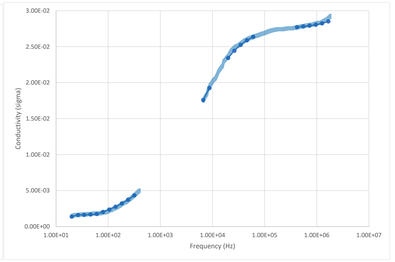

Figure 6: Muscle Conductivity Mean

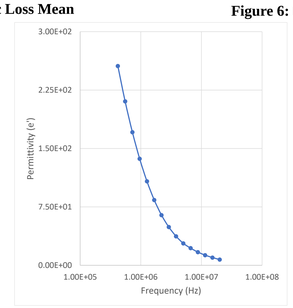

Figure 7: Skin Permittivity Mean

Discussion

The characterization did not vary a lot from sample to sample. Thought they were differences; the behavior was mostly as expected, permittivities decreased and conductivities increased at higher frequencies. The mean of each property, of each tissue, confirmed similar behaviors when looked at together. All tissue samples analyzed in this investigation exhibited the same types of behaviors. The higher beta elevations were observed in all conductivity plots. The sharp decrease from Alpha into Gamma, affecting Beta in the permittivity's, was present in all permittivity tests performed, which 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 as one that could have suffered some blow or anomaly. This could all be coincidental, but instead, we propose that this is just the normal electrical behavior of conductivity in fetus samples. Literature was found to support this, analysis of similar tissues where the results tended to be higher than the expected. In the end, it was observed that though similar, these fetus tissue samples did not adhere to the idealized plots they were meant to follow.

Conclusions

Hypothesis was not supported, as the porcine tissue samples did not adhere to the idealized plots of the properties. All samples presented with some behavior that made it different from the expected shape. Although the hypothesis was not supported, any bioimpedance measurements provide an important method for the non-invasive investigation of tissue structures, to develop the medicine of tomorrow.

Future Work

A more detailed analysis of the layers found in pigs should be made with:

- Adult pigs where tissues are more easily separated and identified.

To see how they affect the electrical properties of the skin more in depth:

- Tissues of different ages or stages of decomposition.
- Tissue samples from a sick or hurt pig.

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