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EFFECT OF COMPRESSION OVER ELECTRICAL ADMITTANCE OF CHICKEN BREAST AND RAT BREAST

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ABSTRACT

Bio-impedance of tissue varies with the amount of applied compression. This paper presents the observed changes *in vitro* in bioimpedance of chicken and rat breast under various levels of compression. Soft tissue admittance at various pressure levels, is measured using bi-polar bioimpedance measurement set up and finger wearable force sensors over Ag/AgCl electrodes. Thus by changing the frequency of driving signal, multi frequency measurements at various pressure levels are obtained. Fitting the Cole-Cole model [1] to the multi-frequency admittance measurements at various pressure levels provides the mapping of parameters showing the relationship between the applied pressure and the admittance of soft tissue. The effect of pressure on bio-impedance parameters in the Cole-Cole model is deduced by means of the least square method and Cole-Cole circuit theory. Studying the bio-impedance of twenty chicken breasts and two rat breasts under compression illustrates the changes in bio-impedance of tissue resulting from the loss of fluid in the tissue.

Keywords: Bioimpedance, soft tissue, admittance, frequency sweep, Cole-Cole model

INTRODUCTION

Electrical Impedance Spectroscopy (EIS) offers a promising avenue of research that has potential for understanding both intracellular and extracellular changes in biological tissue. Multi-frequency EIS is a non-invasive measurement of opposition to the flow of alternating electrical currents at various frequencies through tissue. At clinically relevant frequencies, EIS of tissue reflects the cellular properties of tissue, such as cell packing density, shape and amount of intracellular and extracellular fluid [1].

Present study, presents the observed *in vitro* changes in bioimpedance of chicken and rat breast under various levels of compression. Studying the bioimpedance of twenty chicken breasts and two rat breasts under compression illustrates the changes in bioimpedance of tissue resulting from the loss of fluid in the tissue.

METHODS AND MATERIALS

Experimental Set-up

In this study, *in vitro* bioimpedance measurement is conducted using a standard two point measurement technique [2] on chicken and rat breast tissue. Two Ag/AgCl electrodes from Vermed ("Vermed,") [3] along with Zurich Instruments Impedance Spectroscope HF2IS and transimpedance amplifier HF2TA ("Zurich Instruments,") [4] were used for measurement of tissue bioimpedance properties. Various incremental pressures were applied to the tissue by means of a finger wearable tactile pressure sensor FingerTPS by Pressure Profile Systems ("Pressure Profile Systems-FingerTPS,") [5].

Twenty samples from the same part of ten chicken breasts and two samples from the same part of one rat breast were chosen for the experiment. The samples were cut in a cubic form with length, width and depth of 0.04 m, 0.035 m and 0.02 m respectively. One electrode was placed under the sample and the second electrode was placed on top of the cubic sample. One finger wearable capacitive pressure sensors was worn on the index finger of the right hand. Force sensor was calibrated using a load sensor and a customized

software "Chameleon TVR", available with PPS sensors. This pressure sensor was placed on top of the upper electrode for applying various levels of pressure. Seven force levels (0lb to 3lb) in chicken breast and six force levels (0.5lb to 3lb) in rat tissue were applied to each tissue sample constantly. Simultaneously, the bioimpedance data was collected using EIS Ag/AgCl electrodes. At each pressure level, the frequency was changing from 1 Hz to 1 MHz, thus multi-frequency measurement dataset at 50 different frequencies was obtained.

Theory

The Cole-Cole model is the commonly used Bioimpedance model for tissue admittance.

$$Y = G + jB = G_\infty + \frac{G_0 - G_\infty}{1+(\frac{jf}{f_{yc}})^\alpha} \quad (1)$$

where Y is the whole admittance, G is the conductance and B is the susceptance. G_0 is the admittance at zero driving frequency, G_∞ is the admittance when the driving frequency is infinity, f is the driving frequency, f_{yc} is the frequency at which the imaginary part of the admittance reaches its maximum and α is the dispersion parameter.

The conductance or the real part of admittance and the susceptance or the imaginary part of admittance when plotted in a complex plane form a semicircle as shown in figure 1.

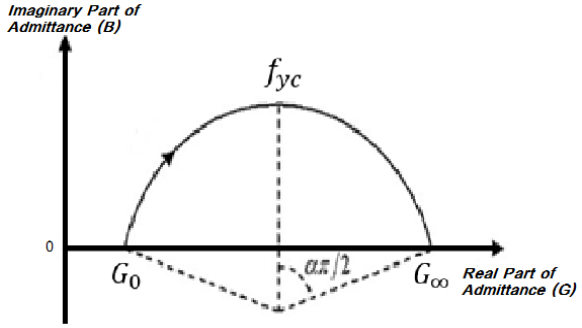


Figure 1: Imaginary part of admittance versus its real part (Cole-Cole arc)

The Cole-Cole model can be fit to the admittance data using the least square method. This optimization method minimizes the summation of the squared error which can be found by subtracting each data point from the fitted data [6].

$$Fitness\ Func. = \min \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (Y_{raw} - Y_{fitted})^2 \quad (2)$$

The Least Square Method was used by Liu *et al* (2007) [7] to fit Cole-Cole model to admittance data and the four parameters were extracted by the following formulas:

$$G_0 = m - \sqrt{r^2 - n^2} \quad (3)$$

$$G_\infty = m + \sqrt{r^2 - n^2} \quad (4)$$

$$\alpha = \frac{2}{\pi} \arccos\left(-\frac{n}{r}\right) \quad (5)$$

$$f_{yc} = \frac{1}{N} \sum_{k=0}^{N-1} f_k \sqrt[\alpha]{\frac{2\, b_k\, r}{(g_k - G_0)^2 + b_k^2}} \quad (6)$$

where (m,n) is the center of the semicircle and r is the radius of the semicircle fitted to the admittance data.

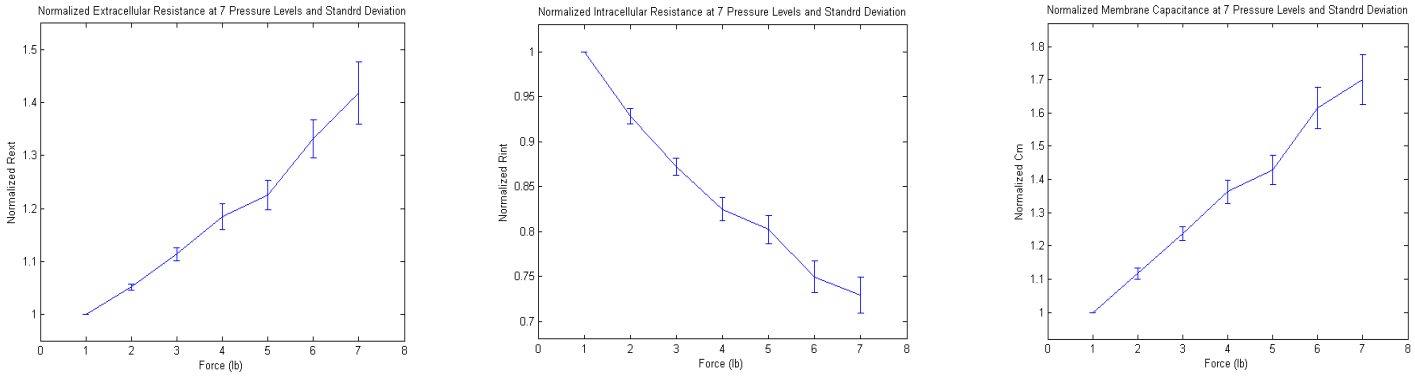
The Cole-Cole model considers the tissue as a circuit containing one resistance and one capacitance in series, which are called intracellular resistance (R_{int}) and membrane capacitance (C_m) respectively and are both in parallel to another resistance called the extracellular resistance (R_{ext}). All these three Cole-Cole circuit parameters can be calculated from the following equations:

$$R_{ext} = R_0 \quad (7)$$

$$R_{int} = \frac{R_0\, R_\infty}{R_0 - R_\infty} \quad (8)$$

$$C_m = \frac{1}{2\,\pi\, f_c\, (R_{int} + R_{ext})} \quad (9)$$

where $R_0 = \frac{1}{G_0}$, $R_\infty = \frac{1}{G_\infty}$ and $f_c = f_{yc} \sqrt[\alpha]{\frac{G_0}{G_\infty}}$.



(a) (b) (c)

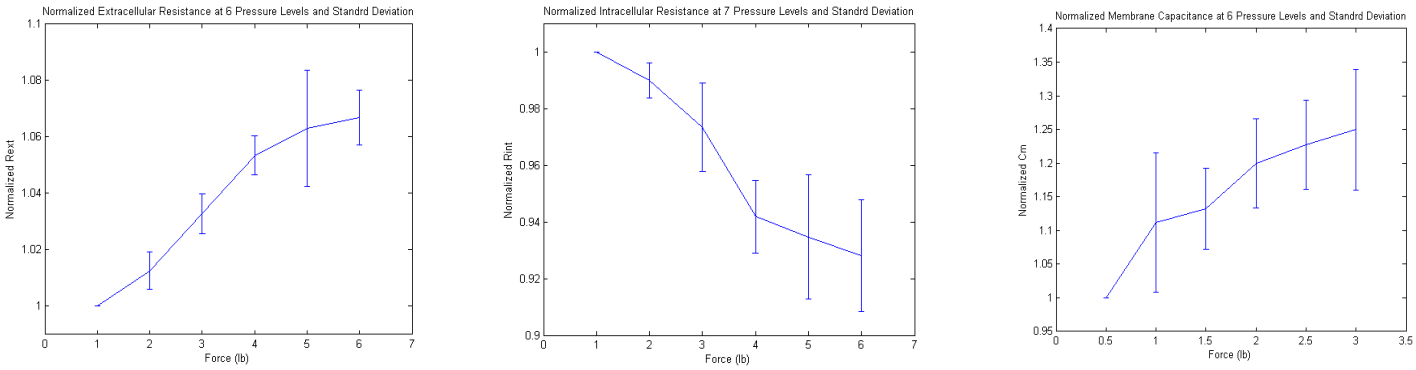
Figure 1: Chicken breast tissue: (a) Normalized extracellular resistance at 7 pressure levels (b) Normalized intracellular resistance at 7 pressure levels (c) Normalized membrane capacitance at 7 pressure levels

RESULTS

Multi-frequency admittance measurements were conducted on twenty chicken breasts and two rat breasts. For each sample, the real and the imaginary parts of admittance were plotted in a complex plane which formed depressed semicircles. By using the least square method, Cole-Cole equation (eq. 1) was fitted to the data and according to the fitted plots and equations 3-6, four electrical parameters, i.e. G_0, G_∞, α and f_{yc} of twenty-two samples were extracted.

Cole-Cole circuit equivalent elements (R_{ext}, R_{int} and C_m) were calculated from the extracted parameters by means of equations 7-9. The equivalent elements of chicken breasts were normalized to their uncompressed values and those of the rat breasts were normalized to their values at the first pressure level. The mean values and the standard error at each pressure level are illustrated in figure 2 for chicken and in figure 3 for rat. The average R_{ext}, R_{int} and C_m and their margins of error in the chicken breast are $455.57 \mp 3.93\ (\Omega)$, $622.27 \mp 7.46\ (\Omega)$ and $(6 \mp 0.098) \times 10^{-9}(F)$. As shown in figure 2(a), the extracellular resistance increases 42% when 3 (lb) force was applied to the tissue compared to the uncompressed tissue. Figure 2(c) illustrates an increase of 70% at the membrane capacitance, while figure 2(b) shows a 28% decrease in the intracellular resistance.

The same behavior in the rat tissue was seen. Figure 3 illustrates an increase of 7% in the extracellular resistance, a decrease of 7% in intracellular resistance and an increase of 25% in the capacitance membrane. The average R_{ext}, R_{int} and C_m and their margins of error in the rat



(a) (b) (c)

Figure 3: Rat breast tissue: (a) Normalized extracellular resistance at 6 pressure levels (b) Normalized intracellular resistance at 6 pressure levels (c) Normalized membrane capacitance at 6 pressure levels

tissue are $603.41 \mp 9.22\ (\Omega)$, $698.06 \mp 78.41\ (\Omega)$ and $(0.37 \mp 0.018) \times 10^{-7}(F)$. The differences in changes of parameters in the chicken tissue and rat tissue show the difference in the structure of these two kinds of tissue.

CONCLUSION

In this study, effect of pressure on the *in vitro* bioimpedance properties of chicken and rat breast tissue was quantified. For this purpose, multi-frequency admittance measurement and compression measurement were conducted using impedance spectroscope with Ag/AgCl electrodes and force fingerTPS sensors, respectively.

The effect of pressure on the bioimpedance properties of chicken breast showed an increase of 42% in the extracellular resistance and 70% in membrane capacitance, and also a decrease of 28% in the intracellular resistance. Similar behavior was seen in the rat tissue. The extracellular resistance and membrane capacitance increased 7% and 25% respectively while the intracellular resistance decreased 7%. These differences illustrate the changes in bio-impedance of tissue resulting from the loss of fluid in the tissue. The difference in chicken and rat breast impedance properties is also due to the difference in the cellular structure of the two kinds of tissue.

Correlating the electrical properties with the mechanical properties of tissue is a future research direction.

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