Measurement of Cell Distribution in Organs with Lissajous of Impedance

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ABSTRACT

The relations between Lissajous' figure of impedance and the cell distribution in the biological tissues were experimentally investigated with the micro-electrode. The micro-electrode of concentric cylinders was manufactured with the stainless steel needles: the diameter of outer needle is 1.20 mm. The electrode was stuck into the normal bovine tissues: the heart, the lever, the kidney, the fatty tissue, or the intestinal mucous membrane. The sinusoidal alternating current of the frequency between one to 1000 kHz was introduced to the circuit with an oscillator. The output voltage was measured at the series resistance. The phase shift between the voltage and the current through the biological tissue was calculated from the effective values of the input voltage, the output voltage, and the phase shift, which was measured at Lissajous' figure between the input and output voltages. The capacitance of the tissue was calculated with an electrical model of one parallel pair of capacitance and resistance. The cell distribution in the tissue was observed with a microscope. The results show that the capacitance increases with the density of cells. This study demonstrates the effectiveness of the Lissajous' figure measurement on the cell distribution in biological tissue.

Keywords: Bio-measurement, Impedance, Micro-electrode, Phase Shift, Lissajous' Figure, Biological Tissue, Cell Distribution

1. INTRODUCTION

Many electrical models on impedance of the biological tissue have been proposed in the previous studies. Impedance on the tissue changes with the frequency of electric signals. This change relates to the distribution of the cells, which act as capacitance. The high frequency signals pass straight through cells, while the low frequency signals go round between cells. The cell distribution was also studied for the detection of the tumor [1].

Various methods have been used to measure biological impedance. The electric current pathway depends on the shape of two electrodes and on the position between them. Capacitance causes the phase shift between current and voltage. Lissajous' figure is often used to measure the phase shift between two sine waves. The present study has investigated the references between Lissajous' figure of impedance and the cell distribution in the biological organs by the measurement with the micro-electrode of concentric cylinders.

2. METHODS

Micro electrode

To keep stable position between two electrodes, the micro-electrode of concentric cylinders was selected (Fig. 1). That was manufactured by the stainless needles: the outer needle of 1.20 mm diameter, 38 mm length; the inner needle of 0.60 mm diameter, 32 mm length. Both cylinders were insulated with silicone grease and with a cylinder of vinyl chloride each other.

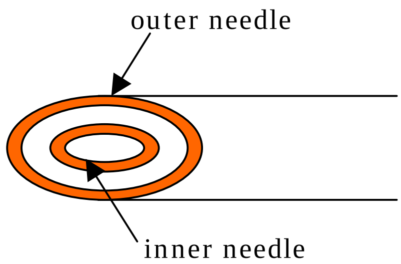

Fig. 1. Micro-electrode.

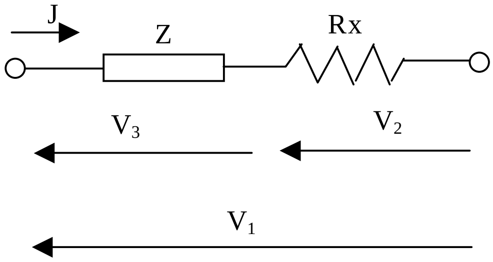

Fig. 2. Electric circuit.

The angle of the electrode end to stick into the tissues is 45 degree.

Materials

The fresh normal bovine tissues were used to measure impedance: the heart, the lever, the kidney, the fatty tissue, or the intestinal mucous membrane. The electrode was stuck into the tissues perpendicularly with the depth of 1.2 mm.

Electric circuit

The load of the electric resistance (Rx) of 985 ohm was connected in series to the electrical circuit including the biological tissue (Z) (Fig. 2). The alternating current in sine wave of the frequency between one to 1000 kHz was introduced to the circuit by an oscillator.

Lissajous' figure

The phase shift angle (A) is calculated from Lissajous' figure between the input voltage and the output voltage (Fig. 3). The output voltage was measured at the connected load of resistance (Rx).

$$\sin(A) = Q / P \tag{1}$$

where P is the amplitude of output voltage, and Q is the intercept of output voltage on the center line at the input voltage equals zero.

Phase shift at the biological tissue

The effective value of voltage loaded on the biological tissue (V_3) is calculated from Eq. (2).

$$V_3^2 = V_1^2 + V_2^2 - 2V_1V_2 \cos(A) \tag{2}$$

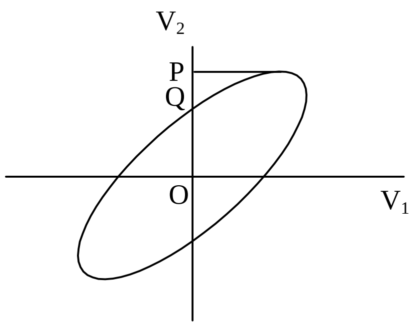

Fig. 3. Lissajous' figure between the input voltage (V_1) and the output voltage (V_2).

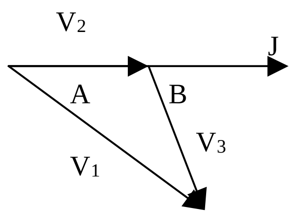

Fig. 4. Relation among phase vectors V_1, V_2, and V_3.

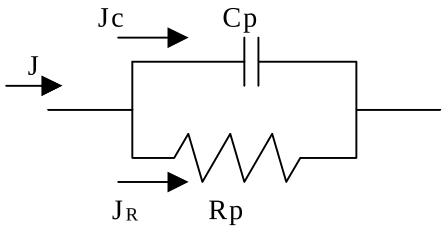

Fig. 5. Electrical circuit model for biological tissue.

where V_1 is the effective value of the input voltage, V_2 is that of output voltage (Fig. 4). The phase shift angle (B) between the voltage (V_3) and the current (J) through the biological tissue (Z) is calculated from Eq. (3).

$$V_1^2 = V_2^2 + V_3^2 + 2V_2V_3 \cos(B) \tag{3}$$

Electrical model

An electrical circuit model (Fig. 5) for the biological tissue with one parallel pair of capacitance (C) and resistance (R) introduces the value of capacitance (Cp) of the tissue from these calculated values at a given frequency (f) (Fig. 6).

$$Jc = J \sin(B) \tag{4}$$

$$J = V_2 / Rx \tag{5}$$

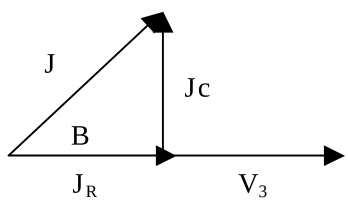

Fig. 6. Relation between phase vectors J and Jc.

where Jc is the current at capacitance, and J is the total current at the circuit.

$$Cp = Jc / (6.28\ f\ V_3) \qquad (6)$$

Cell distribution

These tissues were fixed, dehydrated, embedded, sliced and stained with hematoxylin-eosin staining method. The cell distribution in the tissue was observed with a microscope.

3. RESULTS

The calculated Cp is shown in relation to frequency of electric current in the lever (Fig. 7). The results show that capacitance decreases with the increase of frequency.

Typical cell distribution in each tissue was shown in Fig. 8. Cell distribution is high in the kidney, while no cell is observed in the fatty tissue. The relation between Cp at 10 kHz and density of cells was shown in Fig. 9. The results show that capacitance increases with density of cells.

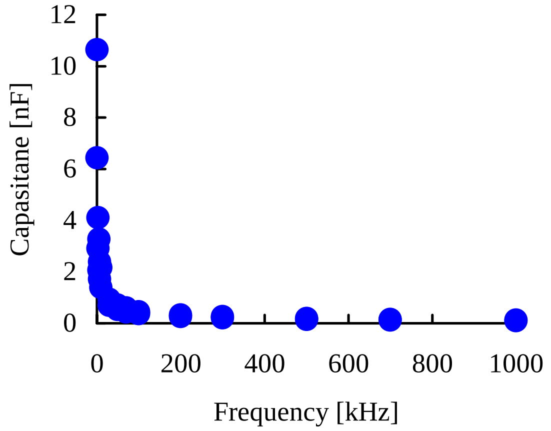

Fig. 7. The relation between Cp and frequency

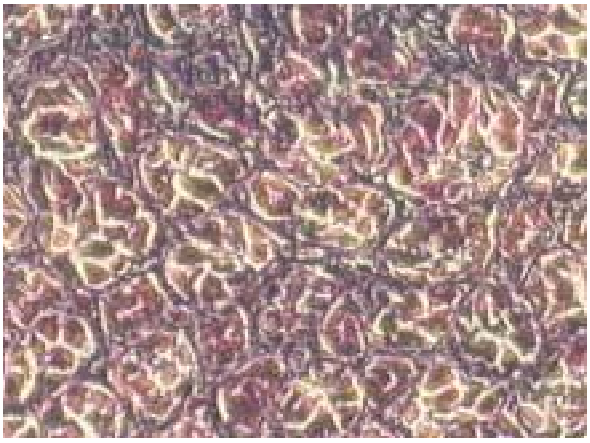

Fig. 8. (a) Cell distribution (kidney). Scale from right to Left : 0.5 mm.

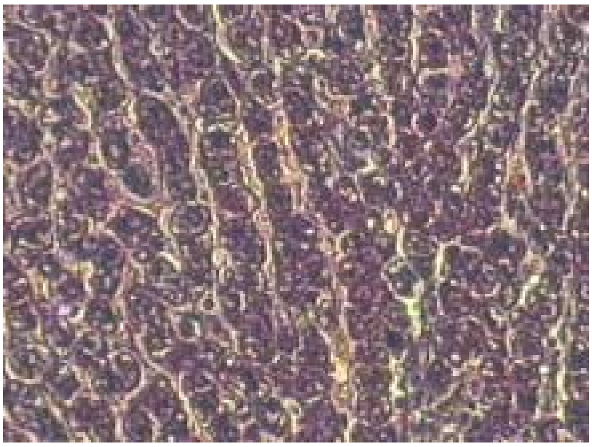

Fig. 8. (b) Cell distribution (lever).

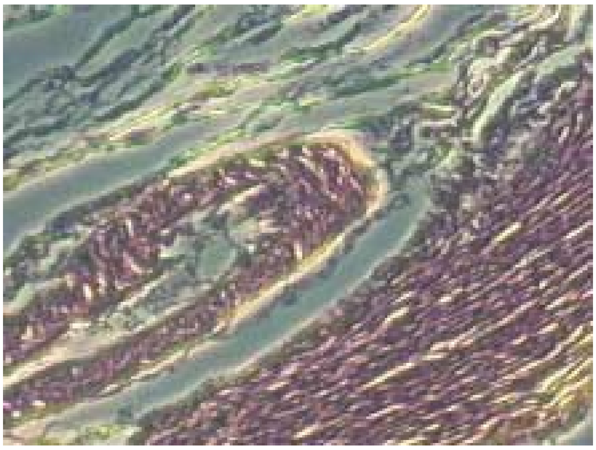

Fig. 8. (c) Cell distribution (intestinal mucous membrane).

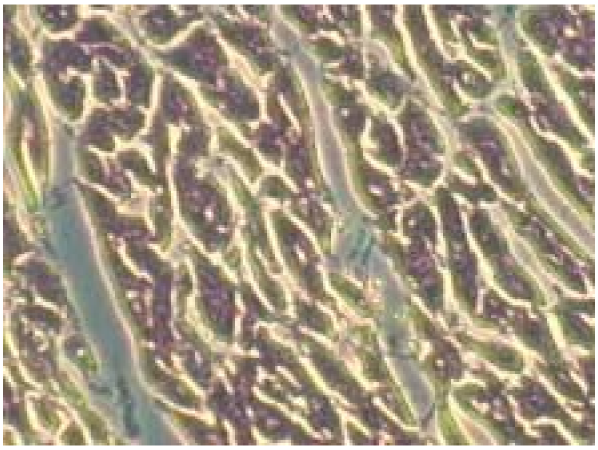

Fig. 8. (d) Cell distribution (heart).

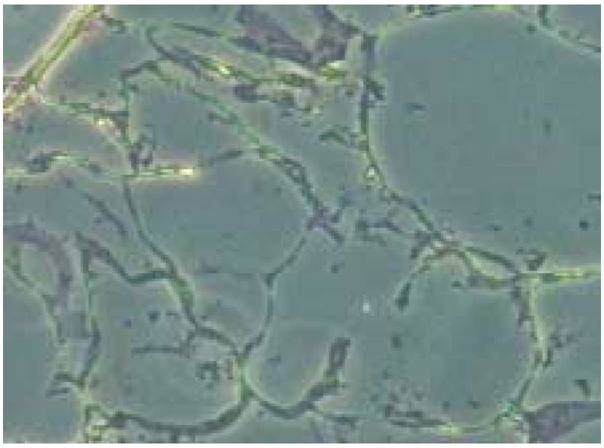

Fig. 8. (e) Cell distribution (fatty tissue).

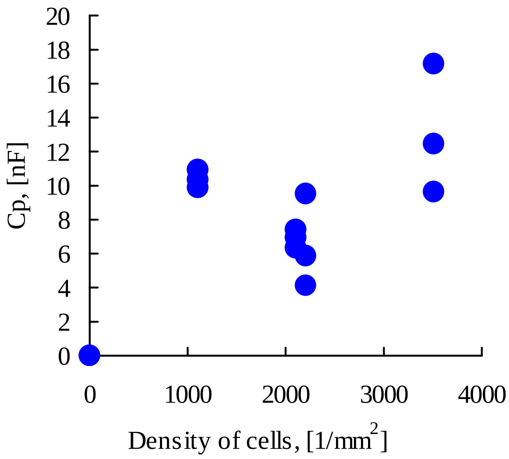

Fig. 9. The relation between Cp and density of cells

4. DISCUSSION

Previous studies about the biological tissue evaluated complex models of impedance, which consists of several elements of resistance and of capacitance. Electric model should include a parallel capacitance according to the frequency characteristic. Three-dimensional internal structure of biological tissue was also tried to estimate with equivalent electric circuit [2].

To stabilize electric current pathway through biological tissue, both the shape and position of electrodes is important. The micro-electrode of concentric cylinders, which is introduced in the present study, has enough stability to measure impedance of biological tissue.

The measurement of local impedance was also applied to detect tumor [1]. The distribution of cells in tumor might be different from that in normal tissue.

5. CONCLUSION

The results show that the capacitance increases with the density of cells. This study demonstrates the effectiveness of the Lissajous' figure to estimate the characteristic of biological tissues from the impedance measurement with the micro-electrode of concentric cylinders.

6. ACKNOWLEDGMENT

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7. REFERENCES

[1] S. Kimura, T. Morimoto, T. Uyama, Y. Monden, Y. Kinouchi and T. Iritani, "Application of Electrical Impedance Analysis for Diagnosis of a Pulmonary Mass", Chest, Vol. 105, 1994, pp. 1679-1682.

[2] N. Momose, Y. Kinouchi, T. Iritani, et al., "Three Dimensional Analysis of Local Tissue Impedance by a Finite Element Method", World Congress on Medical Physics and Biomedical Engineering, 1997, p. 347.