Measurement of Mechatronic Property of Biological Gel with Micro-Vibrating Electrode at Ultrasonic Frequency

Shigehiro Hashimoto

Dept. Biomedical Engineering, Osaka Institute of Technology, Osaka, 535-8585, Japan
hashimoto@bme.oit.ac.jp http://www.oit.ac.jp/bme/

and

Hajime Otani

Cardiovascular Center, Kansai Medical University, Moriguchi, Japan

ABSTRACT

A measurement system has been designed with a micro-vibrating electrode at ultrasonic frequency to measure local impedance of biological gel *in vitro*. The designed system consists of two electrodes, where one of the electrodes vibrates with a piezoelectric actuator. The component of variation at impedance between two electrodes with vibration of one electrode is analyzed at the corresponding spectrum. The manufactured system was applied to measure impedance of a physiological saline solution, a potassium chloride solution, a dextran aqueous solution, and an egg. The experimental results show that the designed system is effective to measure local mechatronic property of biological gel.

Keywords: Biomeasurement, Mechatronic Property, Micro-Vibrating Electrode, Biological Gel, Ultrasonic Frequency, Viscosity

1. INTRODUCTION

Ultrasonic frequency, which is transmitted along a straight line and has concentrated energy, has been applied to several clinical treatments. The transmission property has been used to measure the inside structure in a biological body. The energy also has been used to destroy a hard mass in organs.

A biological body includes various electrolyte solutions. Many studies have tried to estimate the structure of the human body with electric impedance [1]. Macroscopic studies about the impedance of a biological body have been applied to estimate a body fat index. Some studies tried to analyze the structure of organs with measurement of local electric impedance [2, 3]. A methodology for electric impedance measurement has also been studied on blood [4, 5]. The local structure of biological tissue might also be estimated with local mechanical and electrical properties.

To minimize the change of structure by movement of ions with a direct current, an alternating current is applied to measure electric impedance of electrolyte solutions. To measure local impedance, electrodes should be miniaturized, but their high impedance on the electric circuit makes it difficult to detect the impedance of a target object. Four-terminal method, which is usually applied to measure electric resistance with separated terminals for voltage and current, is not appropriate for local measurement of a micro object, because of the larger number of electrodes [6].

In the present study, a novel measurement system has been designed with a micro-vibrating electrode to measure local impedance of biological gel, and has been applied to measure mechatronic property of biological gel *in vitro*.

2. METHODS

Measurement principle

The impedance between two electrodes soaked in an electrolyte solution varies with the distance between them (Fig. 1). When the distance oscillates sinusoidally with a mechanically vibrating electrode, the impedance oscillates, too. The electric oscillation corresponds to the variation of impedance of the local space, where the electrode is vibrating (between A and B in Fig. 1).

When the frequency of input electric alternating voltage is different from the frequency of the mechanical vibration of the electrode, the output electric voltage signal fluctuates. The fluctuating voltage corresponds to the impedance of *dx*. The magnitude of the variation of the voltage is the product of local impedance and electric current, and does not depend on the impedance of the other part of the electric circuit. The variation was analyzed with

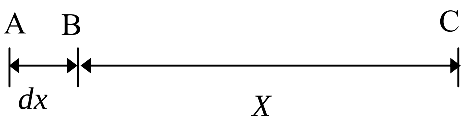

Fig. 1: Distance between two electrodes. One electrode is fixed at point C and another electrode is vibrating between A and B.

spectrum and the amplitude at the corresponding frequency was calculated [7].

Measurement system

The electrode was made of a glass micro-capillary filled with a physiological saline solution. A platinum wire of 0.2 mm diameter was inserted in the center of the capillary with a 0.94 mm inner diameter, and 1.2 mm outer diameter, respectively (Fig. 2). One of the electrodes was vibrated with a piezoelectric actuator (Fig. 3). The measurement system consists of an oscillator, an amplifier, a spectrum analyzer, a phase-contrast optical microscope (Figs. 4-6), a charge-coupled device camera, a recorder, and a monitor.

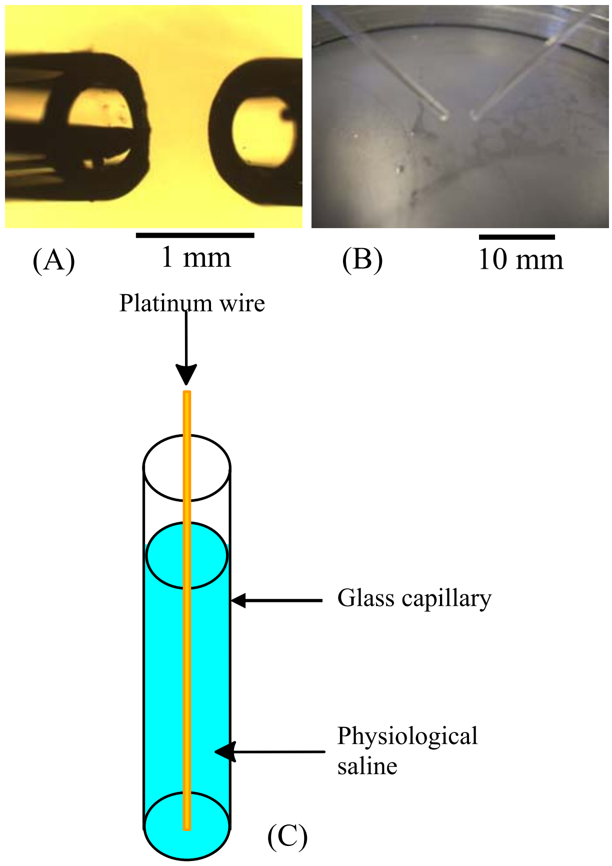

Fig. 2: Electrodes. A, tip: B, two electrodes in culture dish: C, schematic diagram.

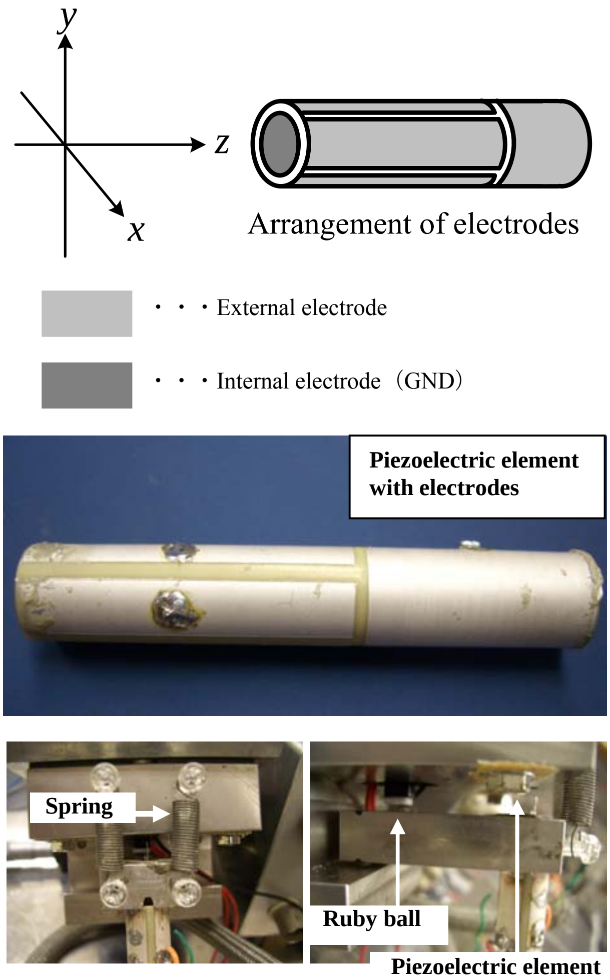

Fig. 3: Piezoelectric actuator.

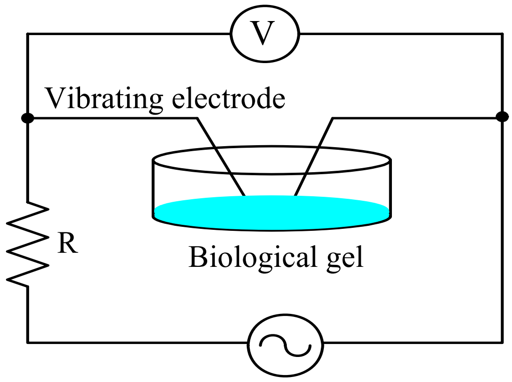

Fig. 4: Electric circuit.

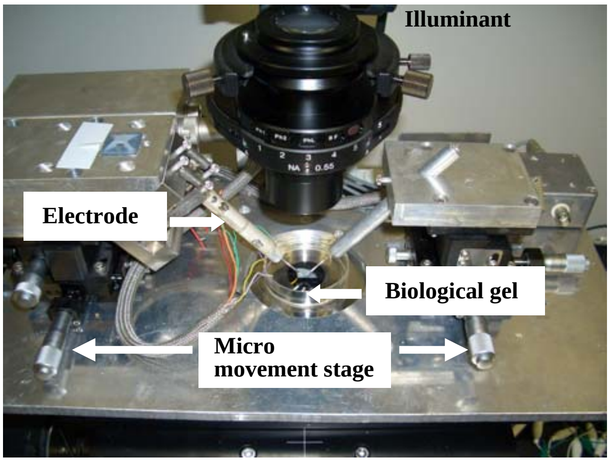

Fig. 5: Measurement system with phase-contrast optical microscope.

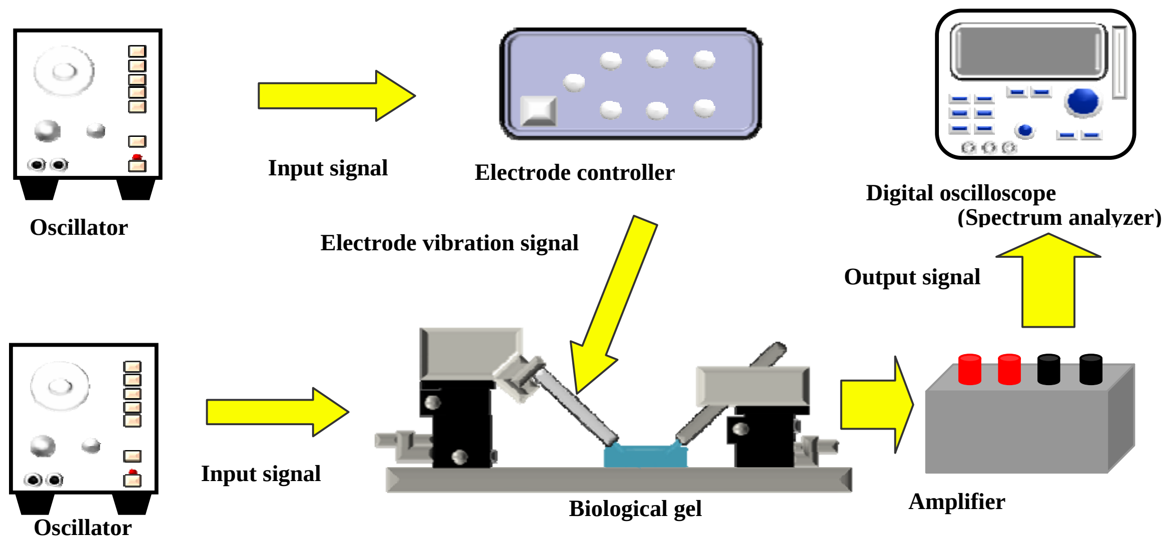

Fig. 6: Electric signal flow in measurement system.

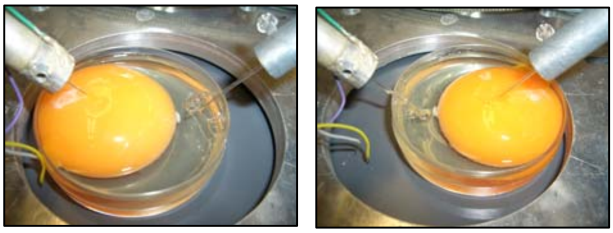

Fig. 7: Measurement on yolk (left) and on albumen (right) in egg.

Experiments

The manufactured system was applied to measure the impedance of a physiological saline solution, a potassium chloride solution, a dextran aqueous solution, and an egg.

In the experiment with a physiological saline solution and with 10 wt% potassium chloride solution, one of the electrodes was mechanically micro-vibrated in the solution of 15 mL in a 60 mm diameter dish. The constant vibrating frequency was chosen between 150 kHz and 400 kHz. The average distance between the two electrodes was 1.3 mm. The impedance was measured with an alternating electric source of 200 mV at 700 kHz.

In the experiment with a dextran aqueous solution, one of the electrodes was mechanically vibrated at 30 kHz in the solution of 5 mL in a 30 mm diameter dish. The average distance between the two electrodes (0.1 mm tip diameter) was 0.3 mm. The impedance was measured with an alternating electric source of 200 mV at 75 kHz.

In the experiment with an egg, one of the electrodes was mechanically micro-vibrated in the yolk or in the albumen of an egg contained in a 60 mm diameter dish. The constant vibrating frequency was chosen between 200 kHz and 350 kHz (Fig. 7). The average distance between the two electrodes was 15 mm. The impedance was measured with the alternating electric source of 200 mV at 700 kHz.

The spectrum of the voltage was analyzed in each test. Viscosity of the solution was measured with a cone and plate type viscometer. Every test has been performed at 25 degrees centigrade.

3. RESULTS AND DISCUSSION

Figure 8 exemplifies input and output signals, and power spectra of the output signal, where both of spectra at the input signal frequency and

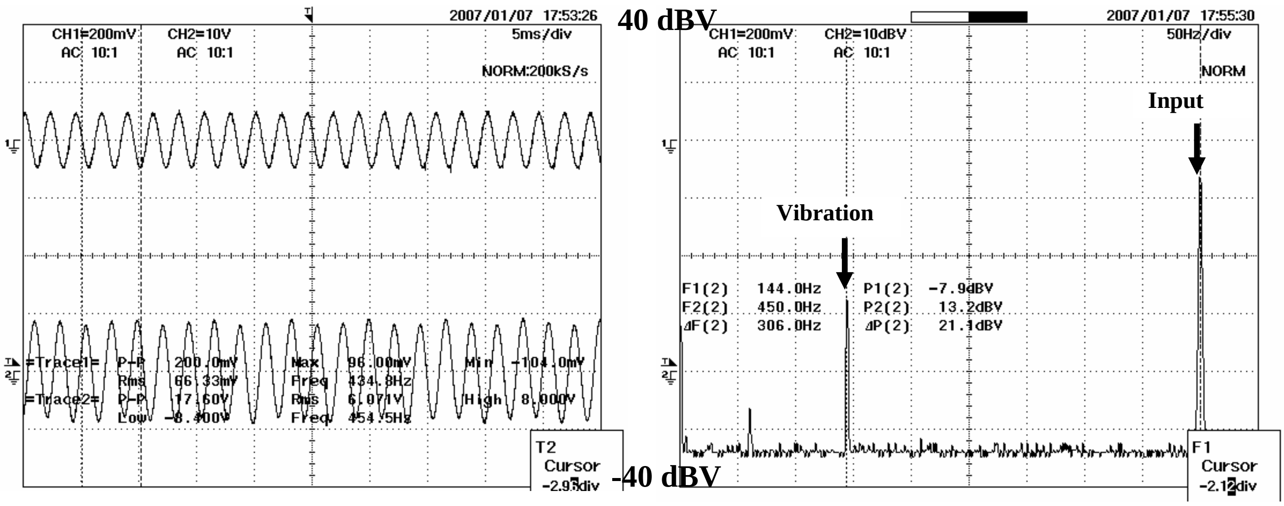

Fig. 8: Input (upper) and output signals tracings with 5 ms/div (left); power spectrum with 50 Hz/div for horizontal axis (right).

at the mechanically vibrating frequency are indicated with arrows. Figure 9 shows the impedance of saline and potassium chloride solutions as a function of vibration frequency. The result shows that impedance of 10 wt% potassium chloride solution is lower than that of saline solution, and tends to decrease with frequency. Figure 10 shows the impedance of dextran aqueous solution as a function of time. The experimental data show that impedance of dextran aqueous solution tends to increase with time, which indicates that the property of dextran solution changes with time, where impedance of physiological saline solution did not change with time. Figure 11 shows the impedance of albumen and yolk as a function of vibration frequency. The figure shows that the impedance of yolk is higher than that of albumen and that the impedance of yolk decreases with frequency. The experimental results show that coefficients of viscosity of physiological saline solution, 10 wt% potassium chloride solution, dextran aqueous solution, albumen and yolk are 0.89 mPa s, 0.90 mPa s, 36 mPa s, 0.44 Pa s and 0.92 Pa s, respectively.

The output signal of the experimental system is independent from the impedance of electrodes and the electrical circuit. The output signal of the system depends on several factors: the concentration of sodium chloride, and the variation of electrolytes [7-10]. It does not

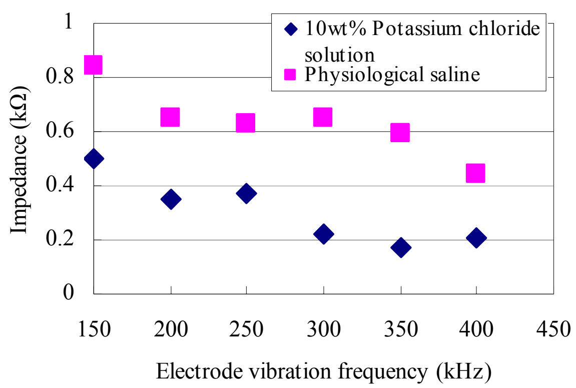

Fig. 9: Impedance of saline and potassium chloride solutions as a function of vibration frequency.

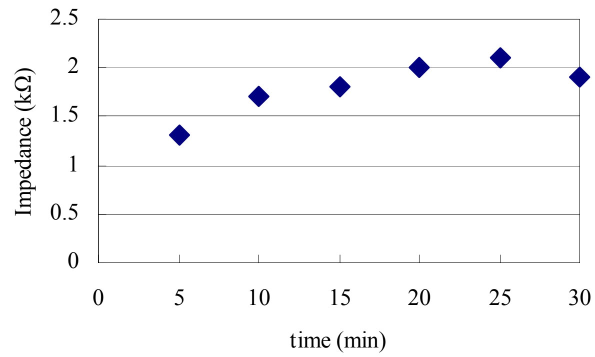

Fig. 10: Impedance of dextran aqueous solution as a function of time.

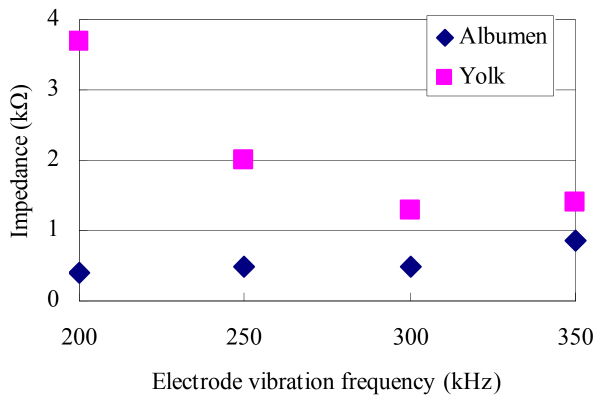

Fig. 11: Impedance of albumen and yolk as a function of vibration frequency.

depend on viscosity at lower frequency (<200 Hz), and on frequency at lower viscosity (<0.01 Pa s) [8].

Four terminals method, in which the voltage and current terminals are separated, is useful to minimize the fraction of impedance of an electronic circuit to measure the voltage. The numbers of electrodes decreases to one in the present system, which has the advantage of being easily accepted to a local area.

4. CONCLUSION

The experimental data show that the designed system is effective to measure the local mechatronic property of biological gel at ultrasonic frequency.

5. ACKNOWLEDGMENT

This work was supported in part by a Grant-in-Aid for Scientific Research and Academic Frontier from the Japanese Ministry of Education, Culture, Sports, Science and Technology.

6. REFERENCES

[1] E. Gualdi-Russo, S. Toselli, "Influence of Various Factors on the Measurement of Multifrequency Bioimpedance", ***HOMO***, Vol. 53, No. 1, 2002, pp. 1-16.

[2] P. Cady, S.W. Dufour, J. Shaw, S.J. Kraeger, "Electrical Impedance Measurements: Rapid Method for Detecting and Monitoring Microorganisms", ***Journal of Clinical Microbiology***, Vol. 7, 1978, pp. 265-272.

[3] C.A. González-Correa, B.H. Brown, R.H. Smallwood, T.J. Stephenson, C.J. Stoddard, K.D. Bardhan, "Low Frequency Electrical Bioimpedance for the Detection of Inflammation and Dysplasia in Barrett's Oesophagus" ***Physiological Measurement,*** Vol. 24, 2003, pp. 291-296.

[4] F. Jasaprd, M. Nadi, A. Rouane, "Dielectric Properties of Blood: an Investigation of Haematocrit Dependence", ***Physiological Measurement,*** Vol. 24, 2003, pp. 137-147.

[5] G.A.M. Pop, T.L.M de Backer, M. de Jong, P.C. Struijk, L. Moraru, Z. Chang, H.G. Goovaerts, C.J. Slager, A.J.J.C. Bogers, "On-Line Electrical Impedance Measurement for Monitoring Blood Viscosity during On-Pump Heart Surgery", ***European Surgical Research***, Vol. 36, 2004, pp. 259-265.

[6] P. Bertemes-Filho, B.H. Brown, R.H. Smallwood, A.J. Wilson, "Stand–Off Electrode (SoE): a New Method for Improving the Sensitivity Distribution a Tetrapolar Probe", ***Physiological Measurement,*** Vol. 24, 2003, pp. 517-525.

[7] S. Yamauchi, S. Hashimoto, Y. Murashige, H. Oku, M. Sakai, T. Sahara, H. Otani, H. Imamura, "Measurement System for Local Electric Impedance of Gel with Vibrating Electrode". ***Proceedings of the 6th World Multiconference on Systemics, Cybernetics and Informatics***, Vol. 13, 2002, pp. 314-319.

[8] T. Sekiyama, S. Hashimoto, Y. Morita, T. Sahara, Y. Morioka, T. Yamanari, K. Yamasaki, H. Kondo, A. Nakajima, H. Otani, H. Imamura, "Measurement System for Mechatronic Property of Biological Electrolyte Solution with Micro-Vibrating Electrode", ***Proc. 8th World Multiconference on Systemics Cybernetics and Informatics***, Vol. 7, 2004, pp. 199-203.

[9] T. Furukawa, S. Hashimoto, Y. Morita, K. Imoto, T. Sahara, K. Yamasaki, H. Kondo, W. Ikeda, M. Yoshiura, H. Otani, H. Imamura, T. Iwasaka, "Measurement of Mechatronic Property of Biological Gel with Micro-Vibrating Electrode", ***Proceedings of the 2nd International Conference on Cybernetics and Information Technologies, Systems and Applications***, Vol. 1, 2005, pp. 276-280.

[10] S. Hashimoto, T. Furukawa, S. Mochizuki, Y. Morita, T. Sahara, Y. Yamanishi, D. Inoue, H. Otani, H. Imamura, T. Iwasaka, "Measurement of Mechatronic Property of Blood during Coagulation with Micro-Vibrating Electrode", ***Proc. 10th World Multiconference on Systemics Cybernetics and Informatics***, Vol. 4, 2006, pp. 177-180.