Parameter Estimation of the Local Tissue Equivalent Circuits for EIT

Yumi KOMAI*, Emiko YASUNO*, Xueli ZHAO*, Yohsuke KINOUCHI*, Tadamitu IRITANI*, Tadaoki MORIMOTO and Mieko TAKEUCHI****

*Facullty of Engineering,
The Univ. of Tokushima
2-1, Minami Josanjima-cho, Tokushima, 770-8506, JAPAN
Phone/Fax : +81-88-656-7475
Email : {komai, kinouchi}@ee.tokushima-u.ac.jp

**School of Health Science,
The Univ. of Tokushima
3-18-5, Kuramoto-cho, Tokushima, JAPAN

Abstract

Electrical impedance tomography (EIT) is 2-D or 3-D image of electrical impedance distribution in a living tissue. It has become expected as a different method to obtain a tissue characteristic for various diagnoses. To realize a practical EIT measurement system, it is important subject to choose a proper configuration of the electrodes, because the EIT is estimated from impedance data, which is non-invasively measured by electrodes. In this study, a new configuration of the electrodes, called *divided electrode*, is proposed here for a short time measurement of bio-impedance in a cross section of a local tissue. Its capability is examined by computer simulations. In the computer simulations, a distributed equivalent circuit is used as a model in the cross section of the tissue. Estimation of impedance parameters is carried out by use of the Newton Method. As results of them, usefulness of the proposed method is confirmed by computer simulations using a typical layered tissue model.

1. Introduction

In presence, density information, such as Ultrasonic imaging, X-CT and MRI, are well used for diagnosis. However, the EIT is considered very useful clinically because structures, physiological function, and physiological state [1] of the tissue caused by cell activities can be monitored. In addition, compared to other CT scanners, the EIT corresponds to the following characteristics: continuation measurement is possible and the best for the monitor of progress. Bio-impedance information has been applied to macro measurement of lung functions [2], blood circulation functions [3], the amount of body moisture [4], the amount of body fat, etc. Though many researches have been reported to realize the EIT for practical use, there remain several problems to be solved. Many theoretical researches in regard to distribution of the bio-impedance have been reported [5,6], but there are few studies put in clinical use by several reasons. One is complicated spatial distribution of the bio-impedance that comes from complicated structure such as biological tissue. Therefore, it is difficult to measure with high-precision and exactly define the measurement result as the medical information. The estimation of spatial bio-impedance is carried out in two stages. At first, biological tissue is expressed with equivalent circuits, which consists of electric parameters. Second, parameters of the equivalent circuit are determined to adapt for the measurement impedance data with the minimum error. Since impedance data and each parameter have a nonlinear relation, we have to carry out numerical calculations. Additionally, many measurement data are necessary for the analysis of the complicated circuit model of biological tissue to obtain high-resolution reconstruction image. Thus, various methods measuring specific part by many electrodes have been proposed. To utilize of EIT, there are some problems to be solved. The problems are inverse problem algorithm for estimating parameters, electrode structure, and configuration for practical use. In our recent studies, we examined usefulness of total bio-impedance for diagnosis of tumor types [7,8] and for estimation of subcutaneous structure [9]. They focused on the local tissue, and measurement electrodes and bio-impedance space distribution estimation has been studied. In this paper, divided electrode is proposed in order to make easy to obtain the bio-impedance distribution in a cross section of local tissue. This electrode consists of guard electrodes and measurement electrodes. The spatial distribution of the bio-impedance is estimated as parameters of the equivalent circuit model. In this model, we consider tumor in tissue and measurement noise. The parameters of the spatial distribution are estimated by use of the Newton Method from the measurement impedance data obtained by the computer simulations, and usefulness of the method is examined.

2. Methods

2.1. Divided electrode

The divided electrode consists of many current electrodes, voltage electrodes, and guard electrodes by slits. The top view of the divided electrode is shown in Fig. 1. The Current electrodes are arranged at the both sides of the voltage electrodes. Since the current is diffused in three-dimensional space and flows in the living tissue, it is difficult to obtain 2-D images. As shown in Fig. 2, the both sides of the measurement electrodes are put by the guard electrodes. More-

over, currents simultaneously flow from all the electrodes. The measurement currents flow in the section of the center without spreading, because guard currents hold down the measurement current from the both sides. Hence, the 2-D impedance distribution can be obtained. Theoretically, this divided electrode is the same as the four electrodes method. The divided electrodes has the shape of plate divided by slits and is used for the skin surface of a local tissue. The central sectional figure of the electrode is shown in Fig. 3. Configuration of current electrodes controls the measurement area and the depth impedance distribution. The voltage electrodes control the impedance distribution of the electrodes-axis direction. By the measurement of currents $(i_1, i_2, ..., i_m)$ and voltages $(v_1, v_2, ..., v_n)$, $\{m \times n\}$ impedance data are obtained at once. Therefore, there are advantages, for example, high-speed and high-resolution measurement is possible. Because of the current flowing simultaneously in the biological tissue, supplied voltage between the corresponding current electrodes is 1V. As a result of calculating the current line of flow and isoelectric line of the circuit model at this time, it has checked that these were as the image of Fig. 3.

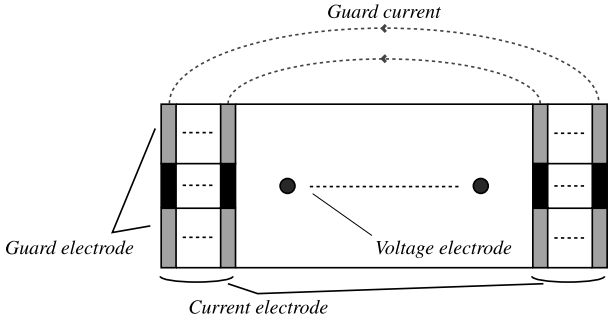

Figure 1: Configuration of a divided electrode: The top view.

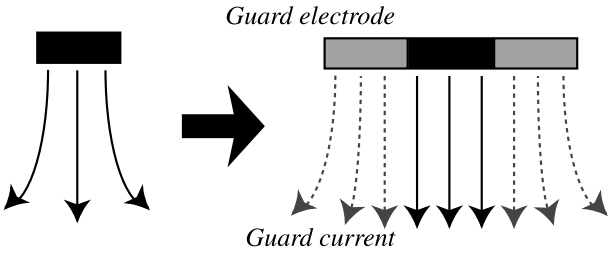

Figure 2: Guard lectrode.

2.2. Distributed equivalent circuit model

Although functions of a living tissues are the same for each tissue, un-uniformity of a tissue exists. Usually, this un-uniformity is expressed by two methods. One of them is supposing that the distribution of electric relief time (time constant of circuit model) is Cole-Cole distribution [10] or Davidson-Cole distribution [11]. Cole-Cole circle rule

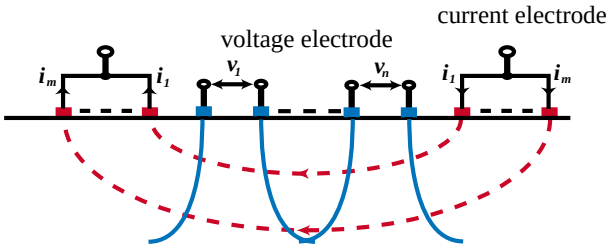

Figure 3: Configuration of a divided electrode: The cross section view.

using the Cole-Cole distribution is suitable for expressing impedance of the large area of β distribution region. However, it is difficult to express the average characteristic of the living tissue separately. Lumped convergence circuit is used as another method. It originates in intracellular resistance, extracellular resistance, and cell membrane capacitance. The lumped circuit can respond to biological tissue structure. However, in the case of three parameters equivalent circuit, it has only one relief time and it expresses a biological tissue in an equivalent circuit on the tissue level. Therefore, neither un-uniformity of the tissue nor tissues thickness with individual difference is reflected. Then spatial distributed equivalent circuit is used as the model considered on the cell level. This is considered that each cell is expressed in an equivalent circuit, much they gather, and the biological tissue is constituted. The equivalent circuit per cell can be expressed with three parameters equivalent circuit. It consists of intracellular and extracellular resistances R_i, R_e and cell membrane capacitance C_m.

Moreover, the cross section of layered tissue as shown in Fig. 4 can be expressed in the 2-D distributed equivalent circuit. In this model, three parameters circuits are connected in the shape of a lattice. The electrodes are point electrodes.

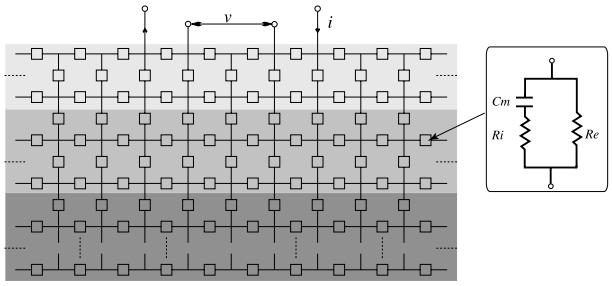

Figure 4: 2-D distribution equivalent circuit model.

2.3. Estimation method

The model connected to N equivalent circuits of three parameters in Fig. 4 is considered. Impedance data $\mathbf{Z}$ measured by K electrodes arrangement can be expressed as following:

$$\mathbf{Z}(\omega) = \left[\mathbf{Z}^{(1)}(\omega), \mathbf{Z}^{(2)}(\omega), \cdots, \mathbf{Z}^{(K)}(\omega)\right]^T$$

Parameter vector $\mathbf{P}$ is expressed as:

$$\mathbf{P} = [R_e(1), R_i(1), C_m(1), \cdots, R_e(N), R_i(N), C_m(N)]^T$$

An initial parameter vector is set to $\mathbf{p_0}$. Applying the Newton Method to each parameter, and the error of measurement data and initial data is given by:

$$\begin{aligned}\delta\mathbf{Z}(\mathbf{p},\omega) &= \mathbf{Z}(\mathbf{p},\omega) - \mathbf{Z}(\mathbf{p_0},\omega) \\ &= \left.\frac{\partial\mathbf{Z}(\mathbf{p},\omega)}{\partial\mathbf{p}}\right|_{\mathbf{P0}} \delta\mathbf{p}. \end{aligned} \quad (1)$$

Measurement frequency are set with $\omega_1, \cdots, \omega_M$, Eq. (1) is defined as:

$$\mathbf{b} = \mathbf{A}\delta\mathbf{p} \quad (2)$$

$$\mathbf{A} = \left[\left.\frac{\partial\mathbf{Z}(\mathbf{p},\omega_1)}{\partial\mathbf{p}}\right|_{\mathbf{P0}}, \cdots, \left.\frac{\partial\mathbf{Z}(\mathbf{p},\omega_M)}{\partial\mathbf{p}}\right|_{\mathbf{P0}} \right]^{\mathbf{T}}$$

$$\mathbf{b} = \left[\delta\mathbf{Z}(\mathbf{p},\omega_1)^T, \cdots, \delta\mathbf{Z}(\mathbf{p},\delta_M)^T\right]^T$$

$\mathbf{A}$ is $M \cdot K \times N$ matrix and $\mathbf{b}$ is N-dimensional vector here. $\mathbf{Z}(\omega)$ can be obtained from measurement data and $\mathbf{Z}(\mathbf{p_0},\omega)$, $\mathbf{A}$ can be obtained from the numerical analysis of the circuit of Fig. 4. Therefore, calculation of the least-squares method of Eq. (2) expressed with Eq. (3) obtained $\delta\mathbf{P}$, which is parameter change from the initial model corresponding to measurement impedance.

$$\delta\mathbf{p} = (2\mathbf{A}^T\mathbf{A})^{-1}(2\mathbf{A}^T\mathbf{b}) \quad (3)$$

3. Results

3.1. Layered tissue with a tumor

The usefulness of this estimated method has been verified by computer simulations using layered tissue model. Here, an equivalent circuit as shown in Fig. 5 is examined in order to complicate a model. The model is triangular lattice type of the 2-D distribution. And a tumor is placed in the center of the second layer of the three-layer structure model, in the figure. Since the tumor has two-layer structure, this model includes 15 parameters. Each parameter value of this model is shown in Table 1. Ten frequency points are measured from 0 to 100 [kHz]. Five current electrodes and five voltage electrodes are arranged at equal intervals, respectively. At this time, the number of measurement data is $10 \times 5 \times 5 = 250$.

The parameters are not estimated from these data. Thus, electrode configuration is devised as shown in the figure. In addition, six voltages are measured. Each parameter is estimated from 300 data using initial values as shown in Table 1. The estimated results of parameters are shown in Table 2.

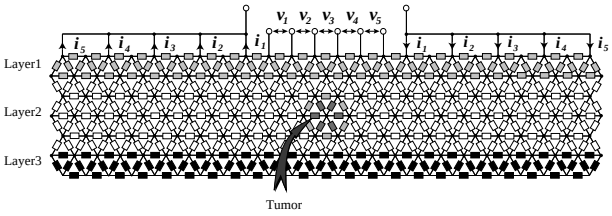

Figure 5: Layered tissue with a tumor circuit model.

Table 1: Model parameters and initial parameters for circuit model in Fig. 5.

	Model parameters			*Estimation results*		
	Re[Ω]	*Ri[Ω]*	*Cm[nF]*	*Re[Ω]*	*Ri[Ω]*	*Cm[nF]*
Layer1	*250.0*	*250.0*	*6.0*	*250.0*	*250.0*	*6.0*
Layer2	*30.0*	*30.0*	*44.0*	*30.0*	*30.0*	*44.0*
Layer3	*83.0*	*83.0*	*16.0*	*83.0*	*83.0*	*16.0*
Tumor1	*63.0*	*63.0*	*21.0*	*63.0*	*63.0*	*21.0*
Tumor2	*57.0*	*57.0*	*23.0*	*57.0*	*57.0*	*23.0*

3.2. Model with noise and un-uniformity of a tissue

In preceding subsection, a complicated model with a tumor is examined. In this subsection, we examine to the model in consideration of measurement noise and the dispersion of a tissue. It calculates about a simple three-layer model with a tumor as shown in Fig. 6. The same value has been used for the parameters for each tissue. But, the parameters are dispersed for each tissue by use of the average values and the rate of standard deviation shown in Table 2. Moreover, noise is added to calculated measurement data. It calculates that noise become less than 1%. There are 20 measurement frequency points and the number of electrodes is 25. 12 parameters are estimated from 500 measurement data. The estimated result of parameters is shown in Table 3. For the data of small noise and dispersion, each parameter was able to be estimated in the precision of satisfaction. And, the parameters is estimated in the almost same precision, as compare with the case of the model in consideration of only measurement noise. Moreover, it is thought that these results reflect of un-uniformity under the voltage electrodes. The precision for parameter average under the electrodes is almost same for the average all parameters. Therefore, it is considered that measurement noise has consequences for the estimated results. The estimated precision of the parameters of the third layer is bad. It considered that sufficient current for the third layer is not flowing from the result. It is necessary to examine the electrode configuration so that current may flow also in a deep layer. Moreover, the precision is improved for a while by increasing measurement voltage and using many data.

4. Conclusions

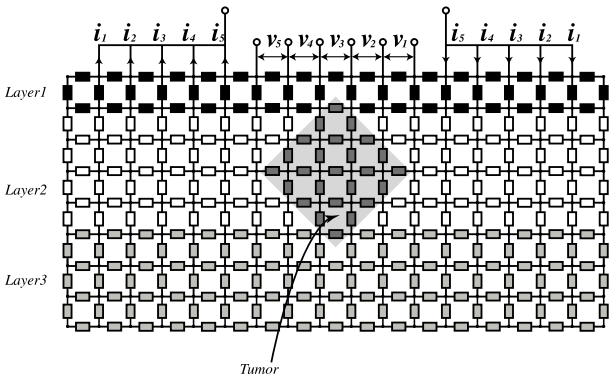

Figure 6: Circuit model.

Table 2: Average parameter and standard deviation.

	Average Parameter			Standard Deviation		
	Re[Ω]	Ri[Ω]	Cm[nF]	Re[Ω]	Ri[Ω]	Cm[nF]
Layer1	250.33	249.97	6.00	2.83	2.89	0.07
Layer2	50.08	50.01	33.96	0.50	0.45	0.45
Layer3	83.03	82.96	15.99	0.80	0.79	0.16
Tumor	109.78	110.05	10.98	1.35	0.95	0.08

In this paper the bio-impedance in consideration of uniformity of tissue has been investigated for the purpose of realization of EIT. In addition, 2-D distributed equivalent circuits composed of intracellular and extracellular resistances R_i, R_e and cell membrance capacitance C_m was considered. It proposed measuring using divided electrode as suitable for practical use. In order to estimate the bio-impedance spatial distribution, parameters of the equivalent circuits are estimated by use of Newton Method. Consequently, it has checked that highly precision parameter estimation was possible for the complicated model by use of a divided electrode. Moreover, it has estimated also to the model in consideration of measurement noise and the dispersion of a tissue. In addition, the estimated result of parameters made into the image. According to the results of the evaluation using computer simulations, it is found from that the proposed method is very useful and practical as a new EIT technology. Future

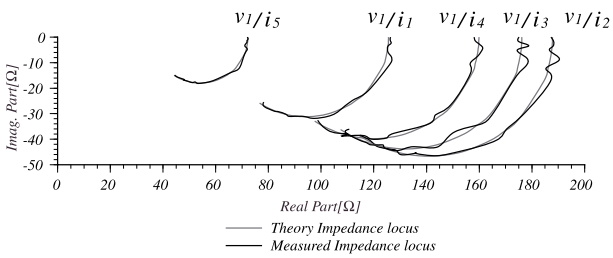

Figure 7: Impedance locus.

Table 3: Estimated parameters and parameter error.

	Estimation results			Parameter Error		
	Re[Ω]	Ri[Ω]	Cm[nF]	Re[%]	Ri[%]	Cm[%]
Layer1	247.35	246.11	5.97	-1.19	-1.54	-0.55
Layer2	50.83	51.39	34.32	1.50	2.76	1.06
Layer3	81.84	79.68	15.24	-1.43	-3.95	-4.69
Tumor	110.74	112.79	11.30	0.87	2.49	2.91

subjects are improvement of the algorithm to a model in the presence of a lot of noise and improvement in resolution, and actual measurement using divided electrode.

References

[1] L. A. Geddes and H. E. Hoff, "The measurement of physiologic events by electrical impedance a re view," Am. J. Med. Electr., Jan.-March, pp. 16-27, 1964.

[2] L. E. Baker, "Applications of the impedance technique to the respiratory system," IEEE Eng. Med. & Biol. Mag., 8, pp. 50-52, 1989.

[3] R. P. Patterson, "Fundamentals of impedance cardiography.," IEEE Eng. Med. & Biol. Mag., 8, pp. 35-38, 1989.

[4] K. Sakamoto, K. Kaneko, M. Ezaki, et al., "Estimation of human wholes body fat volume by electrical impedance method," Jpn. J. Med. Electro. Biol. Eng., 33, pp. 2-9, 1995.

[5] Y. Yamashita et al., "Method and feasibility of estimting impedance distribution in the human tors," Proc. 5th ICEBI, p. 87, 1981.

[6] K. Nakayama et al., "Fundamental study on electrical CT algorithm utilizing sensitivity theorem on impedance plethysmography," Proc. 5th ICEBI, p. 99, 1981.

[7] T. Morimoto, S. Kimura, Y. Konishi, et al., "A study of the electrical bioimpedance of tummors," J. Invest. Surg., 6, pp. 25-32, 1993.

[8] S. Kimura, T. Morimoto, T. Uyama, et al., "Application of electrical impedance analysis for diagnosis of a pulmonary mass," Chest, 105, pp. 1679-1680, 1994.

[9] N. Momose, Y. Kinouchi, T. Iritani, et al., "Three dimensional analysis of local tissue impedance by a finite element method," Wold Congress of Medical Physics and Biomedical Engineering, p. 347, 1997.

[10] K. R. Foster and H. P. Schwan, "Dielectrical properties of tissues and biological materials," a critical review, Critical Reviews in Biomedical Engineering, 17, pp. 25-104 , 1989.

[11] D. W. Davidson and R. H. Cole, "Dielectric relaxation in glycerol, propylene glycol, and n-propanol," J. Chem. Phys., 19, pp. 1484-1490, 1951.