Fast *in vivo* measurements of local tissue impedances using needle electrodes

Y. Kinouchi[1] T. Iritani[1] T. Morimoto[2] S. Ohyama[3]

[1]Department of Electrical & and Electronic Engineering, The University of Tokushima, Tokushima 770, Japan
[2]School of Medical Sciences, The university of Tokushima, Tokushima 770, Japan
[3]Shikoku Instrumentation Co., Tadotsu 764, Japan

Abstract—*The objective of the research is to show an in* vivo, *fast method of measurement of local tissue bio-impedance in the beta dispersion region (0–200 kHz). A needle electrode is used for the purpose. The performances with respect to circuits, electrodes, measurement area and electrical representations are evaluated. A measurement example is shown, and the electrical representations are discussed and compared using it. The method discussed, although invasive, is considered to be useful for local tissue diagnoses concerning structures and physiological functions.*

Keywords—*Bio-impedance, Tissue, Needle electrode, Pulse response method, Measurement, Equivalent circuit*

Med. Biol. Eng. Comput., 1997, 35, 486–492

1 Introduction

BIO-ELECTRICAL IMPEDANCE in the beta dispersion region gives us useful information on biological tissue structures (FOSTER and SCHWAN, 1989) and physiological tissue states and functions (GEDDES and HOFF, 1964; KONISHI et al., 1995). The information is essentially different from that acquired by X-ray imaging, MRI and ultrasonic imaging.

In recent years, bio-impedance has been measured for various biological materials (SCHWAN, 1957; GEDDES and BAKER, 1967). Hitherto it has had applications in many medical diagnoses and examinations, most of which are related to global information about the body or the biological system, e.g., typically, body fluid and composition (THOMAS *et al.*, 1992; SAKAMOTO *et al.*, 1995), the cardiac system (GEDDES, 1989; PATTERSON, 1989) and the respiratory system (BAKER, 1989). These global impedances reflect the total and average properties of a biological system composed of various organs and tissues.

Impedance originally varies with tissue and also with position even in the same tissue, if it contains pathological tissues such as tumours and oedema. In fact, the impedances of breast and lung tumours are different from their surrounding tissues and vary with their type (MORIMOTO *et al*, 1990; 1993; KIMURA *et al.*, 1994).

To obtain the structural and physiological information about the tissue from its bio-impedances, it is necessary to measure the impedances of individual and local tissues. Recently, many diagnostic measurements and processing methods have required electro-physiological inverse problems to be solved, such as source localisation from ECG, MCG, EEG and MEG, where electromagnetic field distributions in the tissue are to be calculated. This requires knowledge of the conductivity and permittivity of each tissue *in vivo*. *In vivo* measurements of local tissue impedance are therefore important and necessary.

Although impedance tomography (KIM *et al.*, 1989; WEBSTER, 1990) can be used for the purpose, its spatial resolution is not yet very high. The purpose of this study is to show a method for measuring *in vivo* bio-impedances of local and sectional tissues, in the millimetre range, and to evaluate the method.

In vivo measurements of bio-impedance for the diagnostic applications described first use non-invasive methods. The methods are, however, difficult to focus on a restricted tissue area, especially for deep tissues. Furthermore, focusing can be difficult, even for shallow tissues, because of subcutaneous fatty tissue. Thin needle electrodes are therefore used here. Needle electrodes, although invasive, are useful for measuring the impedances of restricted and narrow tissue. Needle electrodes also have the advantage that they can be used conveniently in conjunction with biopsies and heating of the tissue (BULLARD and MAKACHINAS, 1978; COSMAN *et al.*, 1988), where impedances can be used for monitoring spatial tissue abnormality in biopsies and temperature in diathermy. Needle electrodes have a possible use for measuring impedance from the lumen and cavity, using catheters and endoscopes (MATSUDA *et al.*, 1987).

Impedances in the beta dispersion region can be measured by a sweeping sinusoidal wave response (ACKMANN and SEITZ, 1984; YAMAMOTO and YAMAMOTO, 1987) and a step response (CHOY, 1978; SINGH *et al.*, 1979). A pulse response method is, however, adopted here, because it is fast, compared with a sweeping sine wave response, and its

First received 21 August 1996 and in final form 4 February 1997
Correspondence should be addressed to Prof. Kinouchi.

frequency range can easily be controlled, compared with a step response.

2 Method

Figure 1 shows the principle for *in vivo* measurement of local tissue impedance using a needle electrode. Here, two types of thin coaxial needle electrode of 0.5 mm in diameter, i.e. oblique and conical types, are considered as a typical electrode, as shown in the Figure. The tips of the needles are exposed as electrodes, and the space between the coaxial needles is filled with epoxy resin. The outer surface is also coated with epoxy resin to insulate the needle from the tissue. A large plate electrode is attached to an appropriate site on the body, e.g. the stomach, as a reference electrode. A current pulse $i(t)$ is applied between the outer electrode of the needle (a current electrode) and the plate electrode, and a resultant response voltage pulse $v(t)$ is measured between the inner electrode of the needle (a voltage electrode) and the plate electrode.

Assuming $I(\omega)$ and $V(\omega)$ to be Fourier transforms of $i(t)$ and $v(t)$, respectively, a measured impedance $Z(\omega)$ is given by

$$Z(\omega) = \frac{V(\omega)}{I(\omega)} \tag{1}$$

A rectangular current pulse can conveniently be used because of the simplicity of the hardware. However, it has useless large-spectrum components in the high-frequency range. A current pulse is advisable to obtain a flat spectrum in the low-frequency range (measurement range) as well as a small spectrum in the high-frequency range. As an approximation for such a pulse, the following current pulse $i(t)$ can be used:

$$i(t) = I_m \cdot \frac{\sin[\pi(t-2\tau)/\tau]}{\pi(t-2\tau)/\tau} \cdot \frac{\cos \alpha\pi(t-2\tau)/\tau}{1-[2\alpha(t-2\tau)/\tau]^2} \quad 0 \leqslant t \leqslant 4\tau$$
$$= 0 \text{ others} \tag{2}$$

which is a part of the pulse that has a raised cosine spectrum. A rolloff parameter $\alpha = 0.5$ gives the waveform of $i(t)$ and its spectrum $I(\omega)$, as shown in Fig. 2, which shows that the requirements above are satisfied approximately. Although the waveform of this pulse is somewhat complicated, it is easily generated by a combination of a memory and a DA converter. If $\tau = 2.5$ µs is chosen (i.e. the pulse width $4\tau = 10$ µs), the main lobe of the spectrum extends to 300 kHz. Impedances in the frequency range 0–200 kHz are measured, because I(200 kHz) is large enough, as $I(200\text{ kHz})/I(0) = 0.506$. As described later, this frequency range is useful to estimate the parameters of an equivalent circuit representing tissue structures. It is difficult to use a sinusoidal wave method extensively to measure impedances at low frequency, e.g. below about 100 Hz, because it needs a long measurement period. The long relaxation time of an electrode polarisation also means a long time is needed for it to settle stably. On the other hand, the pulse response method used here can easily supply impedance data from zero frequency. The peak value I_m should be chosen depending on the measurement position, e.g. if a current pulse is applied to the tissue or a tumour around the breast, I_m will be chosen to be, for example, 5 µA, because currents are restricted to 10 µA by a safety standard in the low-frequency range.

The contact impedance of a plate electrode of 1 cm^2 is approximately 4.6 kΩ at 10 kHz and 2.5 kΩ at 100 kHz. If a plate with an area of 16 × 16 cm^2 is used, its contact impedance is small, at about 18 and 10 Ω at 10 and 100 kHz, respectively. Because the impedance is less than 2% of the impedance measured by needle electrodes (in the range of

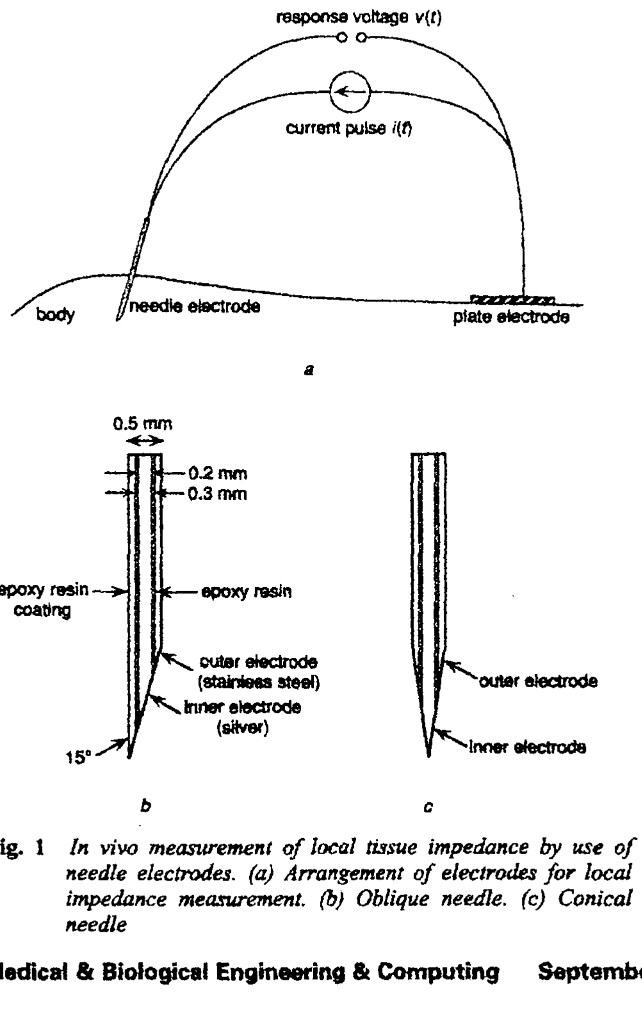

Fig. 1 *In vivo measurement of local tissue impedance by use of needle electrodes. (a) Arrangement of electrodes for local impedance measurement. (b) Oblique needle. (c) Conical needle*

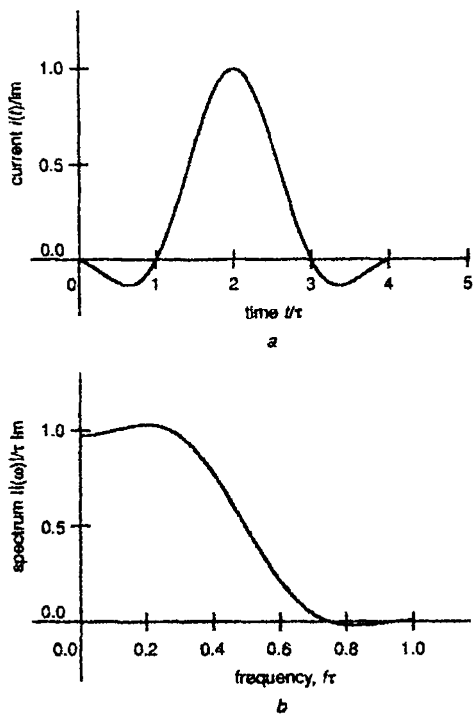

Fig. 2 *(a) Waveform of current pulse i(t) and (b) its frequency spectrum |I(ω)| (approximate raised cosine spectrum)*