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SIMPLIFIED PERMITTIVITY MEASUREMENT OF HUMAN SKIN IN VIVO

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Abstract: We have developed a simple method for measurement of the impedance of biologic tissue in the frequency range (0.5 — 108MHz). An easily fabricated concentric ring probe provide permittivity (dielectric constant) data which correlated well with published data.

Introduction

For some time, scientists have recognized that the electrical properties of the biological tissues reflect underlying biologic properties. The earliest work was done by Hober (1910), McClendon (1926) and Fricke (1925)[1]. Since Foster et al[2] (1979), numerous additional studies have contributed to the fundamental knowledge in this area.

These previous studies were either carried out on *ex vivo* tissue or using animal models. Our emphasis here was on the development of a simple method that could be safely applied to human subjects *in vivo* with potential applicability to screening tests for the maintenance of health or promotion of health. From the pioneering studies cited above and others, we know that tissue properties that can modify electrical parameters include the following: the body temperature, water content (binding water and free water), blood content, blood oxygenation and chemical constituents[3].

Theory and Experiment

We designed a concentric ring type copper probe (see Figure 1(a)), adapting the front end of the design used by Gabriel et al[4], which we modeled as the equivalent circuit shown in Figure 1(b).

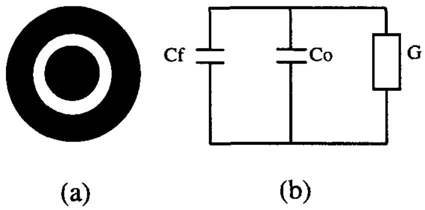

Figure 1. (a) Diagram of the real probe. The diameter of center metal was 2.1mm. the diameter of the inner edge of the metal ring was 7mm, outer edge was 21mm.
(b) Diagram of the equivalent circuit for the probe

In Figure 1 (b), C_f is the capacitance due to the connecting cable and the back of the probe, and C_0 is the capacitance contributed by the front of the probe. C_0 will be changed by touching the skin on front side. The new C_0 will be ε_r times free space C_0. Consequently, once we calibrate the values of C_0 and C_f, we can get ε_r by measuring the value of $\varepsilon_r C_0$ when the probe is in contact with the skin.

We use the radio frequency impedance meter to measure the impedance of the equivalent circuit by touching the probe on the object (see Figure 2). The metal parts, i.e. electrodes were coupled to skin by using a conductive gel (Spectra 360 Electrode Gel, Parker Labs, Inc).

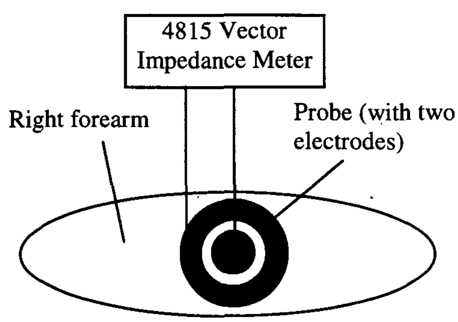

Figure 2. Measurement diagram

According to the modeling of the measurement circuit, we have the formulas:

$$Z = 1/Y, \quad (1)$$
$$Y = G + jB, \quad (2)$$
$$B = \omega(\varepsilon_r C_0 + C_f), \quad (3)$$

where Z is the measured impedance of the circuit, Y is its admittance, G is the conductance between two electrodes, B is the susceptance, and ω is the frequency of exciting signal. From our 4815 RF Vector Impedance Meter, we can read the impedance of the circuit. By using (1), (2), (3), we can get

$$\omega\, \varepsilon_r C_0 = \mathrm{Im}[1/Z] - \omega C_f \quad (4)$$
$$\varepsilon_r = \mathrm{Im}[1/Z] / (\omega C_0) - (C_f / C_0) \quad (5)$$

Using (5), we can solve directly for the relative permittivity of the tissue from the measured impedance (Z) from the vector impedance meter and the previously determined constants, C_f and C_0 at a given measurement frequency, ω.

Data and results

Figure 3 shows that the permittivity is frequency-dependant. When the frequency increases, the permittivity of the tissue decreases. There was a reasonably good fit to a relation of the form "constant1 + constant2 / ω". This figure also shows that our data are reasonably close to those measured by Gabriel et al using time domain spectroscopy techniques[4].

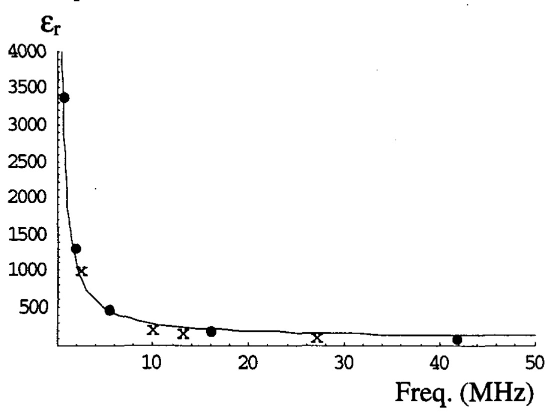

Figure 3. Experimental data which shows the relation between the permittivity and frequency (the circular dot, "•", represents data determined in the present study. The cross "x" represents the data from Gabriel et al[5]).

Conclusion

The experiment result shows that we can measure the electrical properties of tissues in a simple, straightforward way. We expect to use these results as the basis for additional studies to examine the effect of perfusion on tissue permittivity.

Reference

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