Abstract: We have developed a simple method for measurement of the impedance of biologic tissue in the frequency range (0.5 - 108 MHz). 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 constituent[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).

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 \(\varepsilon_0\) times free space \(C_0\). Consequently, once we calibrate the values of \(C_0\) and \(C_f\), we can get \(\varepsilon_0\) by measuring the value of \(\varepsilon_0\) \(C_0\) 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).
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.

**Data and results**

Figure 3 shows that the permittivity is frequency-dependent. 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].

\[
Z = \frac{1}{Y}, \quad Y = G + jB, \quad B = \omega (\varepsilon, C_0 + C_f),
\]

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 \(\omega\) 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

\[
\omega \varepsilon C_0 = \text{Im}[1/Z] - \omega C_f
\]

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, \(\omega\).

\[
\frac{\text{ET}}{\varepsilon_0} = \frac{\text{Im}[1/Z]}{\varepsilon_0 (C_0 - C_f) / C_0}
\]

**Reference**