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# Classification and Applications of Bio-impedance Measurement Techniques

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***Abstract*— Non-invasive nature of bio-impedance measurement technique is the reason for adoption of this technique in wide field of bio-research. This technique is useful in the analysis of variety of diseases. This paper presents basic principle of bio-impedance along with effect of frequency on impedance measurement. Various bio-impedance analysis techniques are discussed here depending on frequency and mathematical models used.**

***Index Terms*-Bio-impedance, Non-invasive measurements, Cole-Cole plot, Multi-frequency analysis**

## I. INTRODUCTION

An alternating current applied to human body flows through the body fluid which has very low electrical resistance. Bio-impedance is an electrical property shown by tissues in human body when electric potential is applied to it. The bio-impedance technique identifies two different types of constituents of human body. Accordingly, human body consists of highly conductive tissues in the form of body water. The other constituent is in the form of body fat which forms a less conductive part of human body. Total impedance offered by human body depends on the proportion of highly conductive and less conductive parts of the body and hence the technique is known as bioelectrical impedance analysis [1]. Bio-impedance analysis can be applied to a variety of constituents of human body including blood samples. Presently, a standard method of blood sample analysis is used for checking blood components to diagnose blood sample infection. But this method has many disadvantages. Frequent blood sampling may result into injuries to subcutaneous tissue, subsequently reason to delusional anemia. It can also lead to inflammation, increase in regional temperature, fever, activation of phagocytes. Impedance measurement has acquired importance because of its non-invasive nature of measurement. Change in environment conditions have less effect on this kind of measurements. Use is at ease while these measurements are going on [2].

## II. BIO-IMPEDANCE ANALYSIS PRINCIPLE

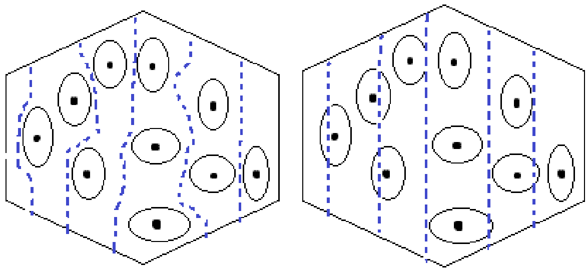
Bio-impedance analysis considers human body as a homogeneous cylinder which consists of arm, legs, and trunk and then calculates total body water and body fat. According to formula for homogeneous cylinder, impedance is directly proportional to length of cylinder and inversely proportional to cross sectional area. This is shown in (1).

$$A \quad z = \qquad (1)$$

In equation (1), $z$ is the impedance to be measured, $\rho$ the resistivity, $L$ the length and $A$ the cross-sectional area. Equation (1) can be rearranged to get (2).

$$z = \rho \frac{L^2}{V} \qquad (2)$$

In equation (2), the volume $V$ of cylindrical conductor is inversely proportional to impedance. When electricity is passed through human body, two components of resistances are observed namely capacitive and resistive. The capacitive component arises due to membranes of cells while the resistance is due to the intracellular and extracellular body water. Hence, impedance of tissue varies with frequency. When frequency of applied signal is very low, impedance of cellular membrane and tissue interfaces is very large to conduct current through cell, the current passes only through extra-cellular fluid and impedance is resistive without reactive component. At high frequencies, capacitive effect of cell membranes is lost and current flows through intracellular fluid. The effect of frequency on current flow is shown in Fig. 1 [3].



(a) (b)

**Fig.1 (a) Low frequency and (b) High frequency current flow through human body**

The resistivity of various body tissues given by International Society for Electrical Bio-Impedance registers [2] is given in Table I.

**Table I Resistivity values of different body tissues**

| Body Tissue Type | Resistivity (Ω .cm) |
|---|---|
| Blood | 150 |
| Urine | 30 |
| Muscle | 300 to 1600 |

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| | |
|---|---|
| Lung | 1275 |
| Fat | 2500 |

According to the resistivity values provided in Table 1, the impedance of fat tissues is highest while that of urine tissues the lowest [2].

## III. METHODS OF BIO-IMPEDANCE ANALYSIS

The methods of bio-impedance analysis are dependent on the frequency of applied alternating current. According to equivalent circuit of tissue shown in Fig. 2, we can write (3).

$$Z = R_0 \| (R_i + X_c) \quad (3)$$

In equation (3), $R_0$ indicates resistance of body due to extra cellular water of tissue, $R_i$ indicates resistance of body due to intra cellular water whereas $X_C$ represents capacitive reactance due to cell membrane and is given by (4).

$$X_C = \frac{1}{2\pi fC} \quad (4)$$

At high frequency $X_c$ will be near zero and for low frequency near zero, $X_c$ acts as open circuit.

$$Z = Z_\infty = R_0 \| R_i \quad (5)$$

$$Z = Z_0 = R_0 \quad (6)$$

Fig. 2 shows equivalent circuit for tissue of human body.

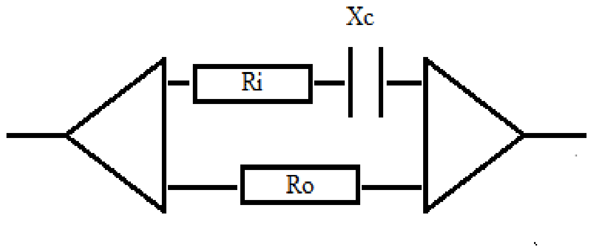


**Fig. 2 Equivalent circuit of tissue**

Thus, impedance Z changes with change in frequency and is dependent on $X_c$. The imaginary as well as real parts of impedance are dependent on frequency as shown in Cole-Cole plot (See Fig. 3) [4]. According to Fig. 3, at very high and very low frequencies impedance value is purely resistive. Therefore, various methods are used for impedance measurements as discussed here.

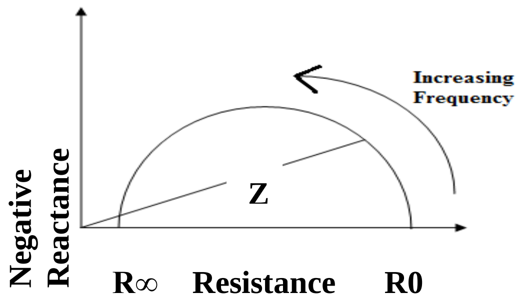


**Fig. 3 Cole-Cole plot**

### *A. Single frequency bio-impedance measurement*

This is mostly used for simple calculations or particularly for measuring body composition. According to tissue to be diagnosed, a single frequency in the range of 10 KHz to 10 MHz is used. For example, diagnosis of blood cell can be done only at high frequencies whereas lean tissue can be checked at frequency less than 100 KHz. This method can calculate fat free mass and total body water but it fails to determine difference between intra-cellular water and extra-cellular water. This method is very simple but has drawback of having less accuracy [2].

### *B. Multi-frequency bio-impedance measurement*

Similar to single frequency measurement empirical linear regression is used by multi-frequency bio-impedance measurement, but it measures impedances at multiple frequencies. Various frequencies like 0, 1, 5, 50, 100, 200, 500 KHz etc. are used for estimation of total body water, fat free mass, intra and extra cellular water. Multi-frequency bio-impedance analysis is less biased and shows more accuracy for prediction of extra-cellular water compared to single frequency bio-impedance analysis while single frequency bio-impedance analysis is more accurate and less biased for total body water. In comparison with bioelectric spectroscopy, multi-frequency bio-impedance analysis is better for predicting total body water. The disadvantage of multi-frequency bio-impedance analysis is its inability to detect changes in distribution and movement of fluid between extracellular and intracellular spaces in elderly patients [2].

### *C. Bioelectric spectroscopy*

In bioelectric spectroscopy, relationship between resistance R and body fluid compartment as well as prediction of R0 and R is established by mathematical modeling and mixture equations. After these empirically derived prediction equations are generated in bio-electric spectroscopy model, great accuracy along with minimal bias is shown by constants and equations for healthy persons whereas modeling techniques need more refinement in disease situations. The potential of bio-impedance spectroscopy can only be exploited if the data are interpreted with adequate algorithm which covers reliable data fitting and a valid fluid distribution model [5].

### *D. Localized bio-electrical impedance analysis*

When whole body bio-impedance is measured, it includes various body segments and hence affected by number of factors such as hydration, fat fraction and geometrical boundary conditions. Therefore, validity of empirical regression model is population specific. Because of these reasons, localized bio-impedance analysis has been proposed which focuses on specific body segment and minimizes interference effect. Scharfetter has calculated local abdominal fat mass by localized bio-impedance analysis. Rutkove found that in patients with neuromuscular disease,

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phase angle and resistivity of limbs decreased with disease progression and normalized with disease remission [6].

## IV. APPLICATIONS

The bioelectric impedance analysis is used to overcome disadvantages of conventional system. Now days, bioelectric impedance analysis has become very popular in the assessment of human body composition which includes conductivity of bioelectrical tissue, distribution of mass and water compartments as well as blood hematocrit. There are many applications of this bio-impedance analysis system [9]. These include detection and study of tumors, detection of decayed or cracked enamel, assess the extent of ischemia in organ transplant, blood cell analysis, dermatological application, bio-technology research on food and pharmaceuticals, pacemaker development and calculating drug delivery rates.

## V. CONCLUSION

Bio-impedance analysis is non-invasive, non-destructive technique which can give great information about properties of living tissues. Bio-impedance analysis equipments, which are recently designed, allow more accurate four terminal measurements of bio materials. Bio-impedance analysis provides estimation of total body water and body composition analysis in healthy individuals and in those with a number of chronic conditions such as mild obesity, diabetes mellitus and other similar medical conditions. Further development is in progress to calculate blood components in order to diagnose patients infected with any blood viruses, such as human immune deficiency virus (HIV), dengue hemorrhagic fever (DHF) as well as blood composition.

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