Methods of Bioelectrical Impedance Analysis

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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- **Non-invasive measurements, Cole-Cole plot, Multi-frequency analysis, bio-impedance.**

I. INTRODUCTION

Bioelectrical Impedance analysis is used to estimate body composition using the difference of conductivity based on the biological characteristic of tissue. Conductivity is proportional to water and electrolyte and it is decreased when cell shape is closer to a round form. Adipose tissue is composed of round shape cell and contains relatively less water than other tissues like muscle, so conductivity is decreased according to the increase of body Bioelectrical impedance analysis (BIA) is a widely used method for estimating body composition. The technology is relatively simple, quick, and noninvasive. BIA is currently used in diverse settings, including private clinicians' offices, health clubs, and hospitals, and across a spectrum of ages, body weights, and disease states. Despite a general public perception that BIA measures "body fat," the technology actually determines the electrical impedance of body tissues, which provides an estimate of total body water (TBW). Using values of TBW derived from BIA, one can then estimate fat-free mass (FFM) and body fat (adiposity). In addition to its use in estimating adiposity, BIA is beginning to be used in the estimation of body cell mass and TBW in a variety of clinical conditions. BIA measures the opposition of body tissues to the flow of a small (less than 1 mA) alternating current. Impedance is a function of two components (vectors): the resistance of the tissues themselves, and the additional opposition (reactance) due to the capacitance of membranes, tissue interfaces, and nonionic tissues. The measured resistance is approximately equivalent to that of muscle tissue. Impedance measures vary with the frequency of the current used (typically 50 kHz, when a single frequency is used). Applications of BIA increasingly use multifrequency measurements, or a frequency spectrum, to evaluate differences in body composition caused by clinical and nutritional status. Many equations are available to estimate TBW and FFM as a function of impedance, weight, height, gender, and age. In actual use, however, BIA calculations of an individual's body fat may vary by as much as 10 percent of body weight because of differences in machines and methodologies used. Equations and their variables differ, as does the choice of a reference method. There is a need for a consensus among experts on the appropriate conditions of use and appropriate applications of BIA. [1].

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).

$$\rho l = A.z \tag{1}$$

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

$$z = \rho \frac{l^2}{v} \tag{2}$$

In equation (2), the volume 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 [2]. 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

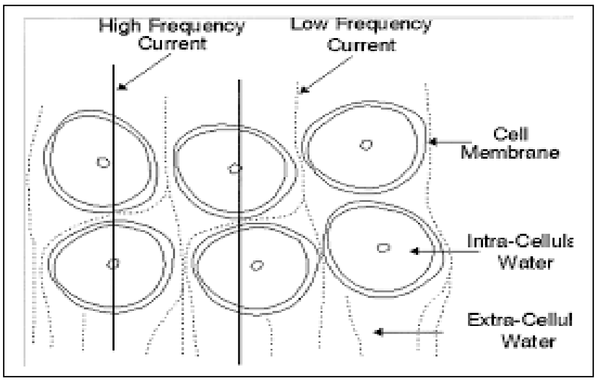

Fig.1 Low frequency and high frequency current flow through human body

III METHODS OF BIOELECTRICAL IMPEDANCE ANALYSIS

The different methods for BIA analysis are single frequency BIA(SF-BIA), Multi-frequency BIA (MF-BIA), bioelectrical spectroscopy (BIS), segmental-BIA are presented in detail in this section.

A. SINGLE FREQUENCY BIA (SF-BIA)

SF-BIA, generally at 50 kHz, is passed between surface electrodes placed on hand and foot (Fig. 2).Some BIA instruments use other locations such as foot-to-foot or hand-to-hand electrodes. At 50 kHz BIA is strictly speaking not measuring TBW but a weighted sum of extra-cellular water (ECW) and intra-cellular water (ICW) resistivities (B25%). SF-BIA permits to estimate fat-free mass (FFM) and TBW, but cannot determine differences in ICW. BIA results are based on a mixture theories and empirical equations.

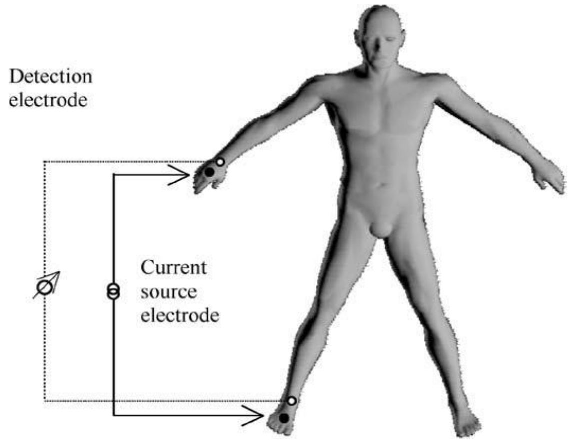

Figure 2 Standard placement of electrodes on hand and wrist and foot and ankle for tetrapolar single (SF-BIA) and multiple-frequency (MF-BIA) BIA.

The latter have been derived in healthy subjects with tight biological homeostasis. Although SF-BIA is not valid under conditions of significantly altered hydration, this does not negate its use to predict absolute FFM or TBW in normally hydrated subjects.7 The relative merits of the various equations have to be discussed, when the normal relationships are not met .

B. MULTI-FREQUENCY BIA (MF-BIA)

As with SF-BIA, MF-BIA uses empirical linear regression models but includes impedances at multiple frequencies. MF-BIA uses different frequencies (0, 1, 5, 50, 100, 200 to 500 kHz) to evaluate FFM, TBW, ICW and ECW. At frequencies below 5 kHz, and above 200 kHz, poor reproducibility have been noted, especially for the reactance at low frequencies.20 According to Patel et al.21 MFBIA was more accurate and less biased than SF-BIA for the prediction of ECW, whereas SF-BIA, compared to MF-BIA, was more accurate and less biased for TBW in critically ill subjects. Hannan noted that MF-BIA, compared to bioelectrical spectroscopy (BIS), resulted in better prediction of TBW and equal prediction for ECW in surgical patients. Olde-Rikkert determined that MFBIA was unable to detect changes in the distribution or movement of fluid between extracellular and intracellular spaces in elderly patients.

C. BIOELECTRICAL SPECTROSCOPY (BIS)

In contrast to MF-BIA, BIS uses mathematical modelling and mixture equations (e.g. Cole–Cole plot (Fig. 3) generate relationships between R and body fluid

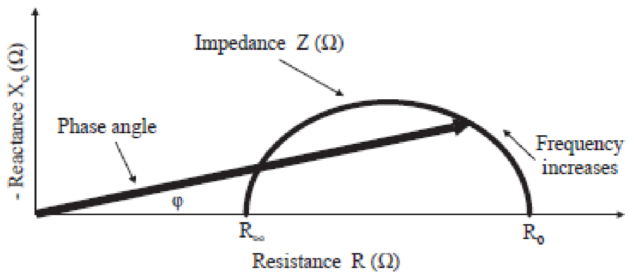

Figure 3. Diagram of the graphical derivation of the Phase angle; its relationship with resistance (R), reactance (Xc), impedance (Z) and the frequency of the applied current.

compartments or to predict R0 and RN and then develop empirically derived prediction equations rather than go to mixture modelling.

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 [3].

D. SEGMENTAL-BIA

Segmental-BIA is performed by either placing two additional electrodes on wrist and foot on the opposite side [4], or by placing sensor electrodes on wrist, shoulder (acromion), upper iliac spine and ankle, or by placing electrodes on proximal portion of the forearm and the lower leg and trunk electrode on the shoulder and the upper thigh. The trunk of the body with its large cross sectional area contributes as little as 10% to whole body impedance whereas it represents as much as 50% of whole body mass. This implies three aspects for body composition analysis by the whole body BIA approach:

(1) Changes of the impedance are closely related to changes of the FFM (or muscle mass or body cell mass (BCM)) of the limbs;

(2) Changes of the FFM (or muscle mass or BCM) of the trunk are probably not adequately described by whole body impedance measurements, and

(3) Even large changes in the fluid volume within the

abdominal cavity have only minor influence on the measurement of FFM or BCM as could demonstrated in patients with liver cirrhosis and ascites undergoing paracentesis .

Segmental-BIA requires prior standardization, particularly when different approaches and different BIA devices are employed. Standardization of the type of electrodes used and their placement is a major concern. Segmental-BIA has been used to determine fluid shifts and fluid distribution in some diseases (ascites, renal failure, surgery), and may be helpful in providing information on fluid accumulation in the pulmonary or abdominal region of the trunk. High relative errors with segmental-BIA for arms and legs: 13–17% for arm FFM and 10–13% for leg FFM. Frequencies higher than 50 kHz did not improve the segmental BIA results. Additional research is needed to examine the accuracy of the segmental BIA. Localized bioelectrical impedance analysis Whole body BIA measures various body segments and is influenced by a number of effects (hydration, fat fraction, geometrical boundary conditions, etc.). Hence the validity of simple empirical regression models is population-specific. For these reasons, localized BIA, which focuses on well-defined body segments and thus minimizes the interference effects, has been proposed. Scharfetter et al [5]. Determined local abdominal fat mass by localized BIA. Rutkove et al [6] determined in patients with neuromuscular disease that phase angle and resistivity of limbs decreased with disease progression and normalized with disease remission and may be useful in the therapeutic evaluation of such diseases.

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 equipment's, 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.

REFERENCES

[1] AH Ar-Rawi, M Moghavvimi, and W Ibrahim, "Novel idea to monitor and measure blood haemoglobin Noninvasively," African Journal of Biotechnology, vol. 9, no. 54, pp. 9295- 9306, Dec 2010.

[2] M.A. Kadir, K.S. Rabbani, and A.J. Wilson, "Development of a multi-frequency system for medical applications of focused electrical impedance method (FIM) appropriate for developing countries," in 7th International Conference on Appropriate Healthcare Technologies for Developing Countries, London, 18-19 Sept. 2012, pp. 1-6.

[3] Liang-Yu Shyu, Meng-Chieh Tsai, Dong-Feng Yeih, and Weichih Hu, "A novel system for continuous peripheral arterial pressure-volume loop measurement," in Annual International Conference of the IEEE Engineering in Medicine and Biology Society(EMBC), Boston, MA , Aug 30 2011-Sept. 3 2011, pp. 4340 – 4343.

[4] Organ LW, Bradham GB, Gore DT, Lozier SL. Segmental bioelectrical impedance analysis: theory and application of a new technique. J Appl Physiol 994; 77:98–112.F. S.

[5] Scharfetter H, Schlager T, Stollberger R, Felsberger R, Hutten H, Hinghofer-Szalkay H. Assessing abdominal fatness with local bio impedance analysis: basics and experimental findings. Int J Obesity Rel Metab Disord 2001; 25:502–11

[6] Rutkove SB, Aaron R, Shiffman CA. Localized Bioimpedance analysis in the evaluation of neuromuscular disease. Muscle Nerve 2002;25:390–7