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Bioelectrical Impedance Analysis at Inner Forearms of the Human Body using Bioelectrical Impedance Measurement System

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ABSTRACT

The bioelectrical impedance (BI) at the inner forearms was measured using bioelectrical impedance measurement system (BIMS), which employs the multi-frequency and the two-electrode method. Experiments were performed as follows. First, while applying a constant alternating current of 800A to the inner region of the forearms, BI (Z) was measured at nineteen frequencies ranging from 5 to 500 kHz. The prediction marker (PM) was calculated for right and left forearm. The resistance (R) and the reactance (X_c) were simultaneously measured during impedance measurement. Second, a Cole-Cole plot (relationship between reactance and resistance) was obtained for left and right forearm, indicating the different characteristic frequencies (f_c). Third, the phase angle was obtained, indicating strong dependence on the applied frequency.

Key words: Bioelectrical Impedance, Impedance Analyzer, Resistance (R), Reactance (X_c), Phase Angle (Θ), Extracellular Fluid (ECF), Intracellular Fluid (ICF)

1. INTRODUCTION

Bioelectrical impedance analysis (BIA) is a safe, practical, and non-invasive method for measuring components of the biological tissues and biological materials with ease [1-4]. BIA relies on the conduction of a radio-frequency electrical current by the extra cellular fluid (ECF, water, interstitial fluid, plasma, and electrolytes), cell membrane (resistance and reactance), and intra cellular fluid (ICF) in the tissues of body [5]. Many studies on BIA have been carried out in order to analyze the composition of living tissue or biological materials [6-11]. Deurenberg *et al.* [6] examined the application of bioelectrical impedance (BI) method to measure the composition changes in the human body. Kushner *et al.* [7] utilized BIA to determine the extracellular water (ECW) and total body water (TBW) in a normal human body. Scheltinga *et al.* [8] found that BIA could detect minimal alterations in volume of body fluid. Miyatani *et al.* [9] investigated the validity of BI and ultrasonographic methods in predicting the muscle mass of upper arm. Kanai *et al.* [10] discussed the problems of measuring ICF and ECF distribution in living tissues by means of BI. They reported that

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the ICF and ECF distribution were related to some pathophysiological parameters, such as blood circulation, metabolism of tissues, and the electrolytic concentration of ICF and ECF. Furthermore, Kim *et al.* measured segmental BIA at the popliteal region of the body using bioelectrical impedance measurement system [11]. However, conventional researches conducted for analyzing the bioelectrical impedance mainly dealt with the changes related to the resistance, the impedance, and the body composition using applying a single-frequency (50 kHz).

In this study, BI at the inner region of forearms was measured using BIMS with multi-frequency analysis and two-electrode method. In particular, various parameters such as the prediction marker, the phase angle, the characteristic frequency, and Cole-Cole diagram as well as the impedance (resistance and reactance) were to analyze. To do these, the following experiments were carried out.

First, BI was measured at nineteen frequencies ranging from 5 to 500 kHz after attaching electrodes (Monitoring electrode, 3M Co., USA) to the inner region of forearms. When alternating current having frequency higher than 50 kHz was applied to the forearms (left and right), BI was significantly decreased. The resistance and the reactance were simultaneously measured as a function of applied frequency during BI measurement. Second, a Cole-Cole plot, the relationship between reactance (X_c) and resistance (R), was acquired from measured BI. The characteristic frequency (fc), in which the maximum reactance occurs in the frequency range, was obtained for left and right forearms. Third, the phase angle (Θ) was obtained as a function of frequency, indicating strong dependence of phase angle (Θ) on the applied frequency.

2. RESEARCH METHOD

2.1 Equivalent Circuit of ECF, Cell Membrane, and ICF

Total body water (TBW) occupies 60% of the weight depending on the age, the sex, and the obesity. The intracellular fluid (ICF) accounts for about 40% of TBW and the extracellular fluid (ECF) about 20% of TBW. Further, the interstitial fluid (ISF) occupies about 15% of ECF and the plasma about 5% of ECF. Despite having lower protein content, the composition of ISF is similar to that of the plasma. Cells constituting the human organ consist of ICF and ECF that behave as an electrical conductor, while the cell membrane acts as an electrical capacitor [12].

Fig. 1 indicates an equivalent circuit of the cell model, and Table 1 lists descriptions of the indicated symbols.

Since the resistance (R_m) and the capacitance (C_m) of the cell membrane are connected in parallel, the reactance (X_c) of the cell membrane in Fig.

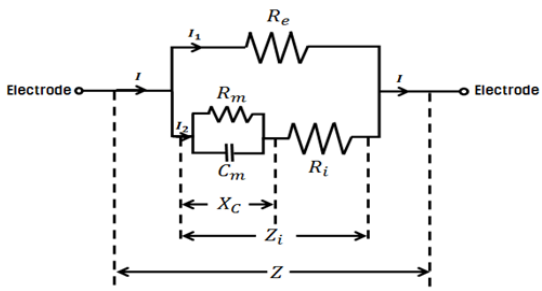

Fig. 1. Equivalent circuit of cell model consisting ECF (R_e), the cell membrane (C_m), and ICF (R_i).

Table 1. Meaning of symbols indicated in Fig. 1

Symbol	Description
Cm	Capacitance of cell membrane
Rm	Resistance of cell membrane
Re	Resistance of ECF
Ri	Resistance of ICF
Xc	Reactance of cell membrane
Zi	Impedance of Xc and Ri (ICF)
Z	Impedance of Zi and Re (ECF)
I	Current through both ECF and ICF
I_1	Current through only ECF
I_2	Current through both cell membrane and ECF

1 can be represented by Eq. (1):

$$X_C = \frac{1}{\frac{1}{R_m} + j\omega C_m} = \frac{R_m}{1 + j\omega R_m C_m} = \frac{R_m}{1 + j2\pi f R_m C_m} \quad (1)$$

Impedance (Z_i) of the cell membrane and the ICF can be represented by Eq.(2):

$$Z_i = X_C + R_i = \frac{R_m}{1 + j2\pi f R_m C_m} + R_i \quad (2)$$

The total impedance (Z) - which consists of the reactance (X_c) of the cell membrane, the resistance (R) of the intracellular fluid, and the resistance (R_e) of the extracellular fluid - can be represented by Eq. (3):

$$Z = \frac{1}{\frac{1}{R_e} + \frac{1}{Z_i}} = \frac{R_e Z_i}{R_e + Z_i} \quad (3)$$

The reactance (X_c) of the cell membrane depends on the applied frequency. When the frequency is high, Z is decreased since X_c in Eq. 1 is decreased and Z_i in Eq. 2 is also decreased. Conversely, when the applied frequency is low, Z is increased as the opposite phenomenon occurs.

2.2 Bioelectrical Impedance Measurement System

Bioelectrical impedance measurement system (BIMS) was described in our previous paper [13]. BIMS consisted of a main control unit (MCU, ATmega128, NewTeC Co., Korea), multi-frequency generation (MFG) unit, automatic gain control (AGC) unit, constant current source (CCS), electrode, preprocessing part, and PC. MCU outputted the control command with respect to the frequency generated by MFG, and controlled the overall function of BIMS. Frequencies of 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 150, 200, 250, 300, 350, 400, 450, and 500 kHz were generated in the MFG unit. The output voltage of frequency generated by MFG was automatically controlled in AGC unit. Constant alternating current (AC) of 800 μA was generated in CCS. While the AC flew into the inner region of the forearms, the segmental BI was measured and then transferred to PC after preprocessing.

PC program was developed using LabVIEW (LabVIEW 2010, National Instruments Co., USA) to control BIMS and analyze the measured BI values. PC program was configured to set parameters such as the starting frequency, the incremental frequency range, the frequency setting number, and the output voltage. Measured BI was displayed in the form of bode diagram and Cole-Cole plot, tables, and then stored in PC.

3. EXPERIMENTAL RESULTS

The experimental subjects were ten male adults with a mean age of 26.4 years (±2.7 years), an average height of 174.3 cm (±3.2 cm), and an average mass of 73.8 kg (±3.6 kg). Prior to the experiment, the purpose and method of this study were explained to the subjects, and their consent was obtained. This study was approved by the ethics committee of Inje University Institutional Review Board for Clinical Studies (Document number: 2014250).

Each experiment was conducted five times for 10 subjects using BIMS. Each measurement was performed after a 10-minute break. The BI was measured using multi-frequency BIMS with two-electrode method. Ag/AgCl electrode (Monitoring electrode, 3M Co., USA) was used for electrode. Nineteen different frequencies generated from MFG unit were sequentially applied to electrode attached to the inner region of left and right forearms through AGC and CCS. Then, a constant AC of 800 uA having frequency ranging from 5 to 500 kHz was applied to the electrode. In particular, the impedance (resistance and reactance) according to the applied frequency, and various parameters such as the prediction marker, the phase angle, the characteristic frequency, and Cole-Cole diagram were analyzed. To do these, the following experiments were carried out.

Fig. 2 shows Z as a function of the frequency

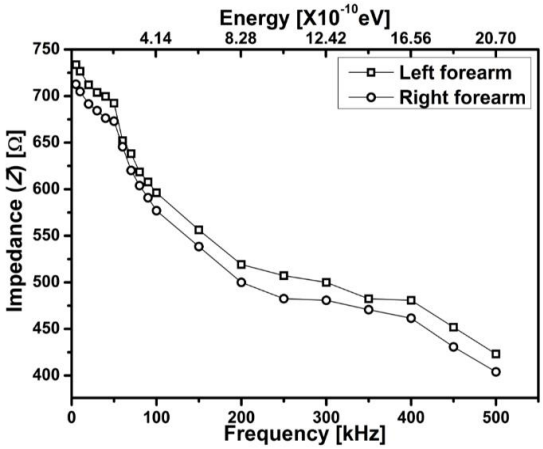

Fig. 2. The measured bioelectrical impedance vs. frequency and energy.

(f) and energy (eV) when electrodes with separation of 7 cm were positioned on the inner region of forearms. At 5 kHz, BI value was 733.71 Ω for a left forearm and 712.70 Ω for right forearm, respectively. When the applied frequency increased from 5 to 50 kHz, the BI was reduced because the current flews only in ECF. However, when the applied frequency increased from 50 to 100 kHz, the BI was significantly reduced since the current flew in ICF as well as ECF. Thereafter, the BI was gradually decreased when the applied frequency increased up to 500 kHz. These results are in agreement with the result reported by Lukaski *et al.* [14]. Fig. 2 also exhibits high bioimpedance for left forearm (733.71 Ω at 5 kHz and 692.31 Ω at 50 kHz and right forearm (712.70 Ω at 5 kHz and 673.28 Ω at 50 kHz) because segmental BI was measured at inner region of forearms and the surface area of Ag/AgCl electrode (Monitoring electrode, 3M Co., USA) was small 0.785 cm^2, whereas BI of a forearm was reported to be about 270 Ω using body composition analyzer (Inbody 720, Biospace Co., Korea) [15]. In addition, the BI at a right forearm was slightly lower than that at a left forearm. This is because eight of ten experimental subjects were right-handed (with higher muscle mass on the right forearm).

The prediction marker (PM) is the ratio of the bio-impedance (Z) at 200 kHz to that at 5 kHz. At 5 kHz, the applied AC cannot penetrate the cell membrane and therefore flows through ECF (R_e), as seen in Fig. 1 However, at 200 kHz, the applied AC is strong enough energy to penetrate the cell membrane and then flow through ICF (Z_i) as well as ECF (R_e), as seen in Fig. 1. The higher PM is, the healthier the body cells are. The PM closer to 1.00 indicates poor cellular health or extreme fluid [16]. In this study, PM was 0.702 for a right forearm whereas PM was 0.708 for a left forearm.

Fig. 3 shows the resistance (R) and reactance (X_c) as a function of applied frequency. Since the resistance accounts for about 99% of the bioimpedance (Z), the resistance curves were similar to the bioimpedance curves in Fig. 2. Left side shows R vs. frequency for left and right forearms, whereas right side shows X_c vs. frequency for left and right forearms. As shown in equivalent circuit consisting of ECF (R_e), cell membrane (C_m), and ICF (R_i) in Fig. 1, the R was high (733.26 Ω for left forearm and 711.21 Ω for right forearm) at 5 kHz. When the AC having a low frequency (5 kHz) was applied to the human tissue, the AC flew through ISF and could not penetrate cell membrane. Thus, the R was high. When a medium frequency (10~50 kHz) was applied to the human tissue, R was gradually decreased since the AC

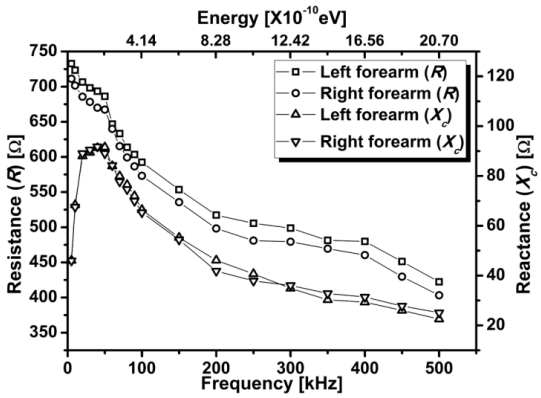

Fig. 3. Resistance and reactance vs. frequency for left and right forearms.

flew mainly through ECF (ISF and plasma). However, when the AC having a high frequency (50 kHz) was applied to the human tissue, R was significantly decreased because the AC flew through ECF and ICF. In addition, the right side in Fig. 3 shows X_c vs. frequency for left and right forearms. When the applied frequency was lower than threshold (50 kHz), the AC could not penetrate the cell membrane so that the current flew through ISF. However, when the applied frequency was higher than threshold (50 kHz), the AC flew through both ECF and ICF. The X_c was gradually decreased further when the applied frequency was increased up to 500 kHz.

The movement of the AC in the different path (Fig. 1) of the cell model at different frequencies can be usefully displayed as a Cole-Cole plot (figure 4) [17]. At very low frequency (~Hz), the BI is only resistive, corresponds to the extracellular resistance, and AC cannot flow through the ICF because it cannot flow through cell membrane capacitance. As the applied frequency increases, the phase angle (Θ) gradually increases as high current is diverted away from the ECF resistance, and passes through the capacitance of the ICF path. At high frequencies (>500 kHz), the ICF capacitance becomes negligible, so current enter the parallel resistance of ICF and ECF

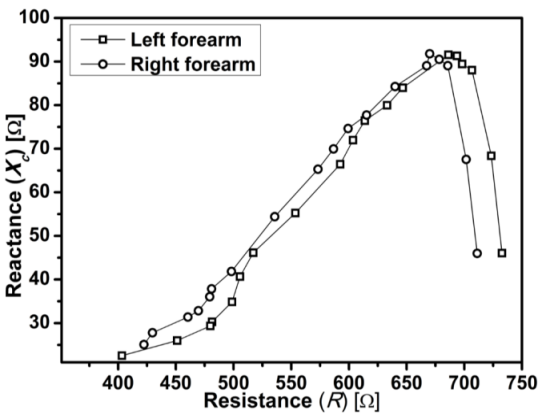

Fig. 4. Cole-Cole diagram (reactance vs. resistance) for left and right forearms.

compartment. The cell membrane reactance, which is proportional to the muscle mass and the structural integrity of cell membrane [18], is now nil, so the entire bioimpedance (Z) again is just resistive and so returns to the resistance axis. Between these, the AC flow through the capacitive path reaches a peak.

The f_c is the frequency at which the reactance (X_c) is highest and a useful parameter for evaluating pathophysiological function of cell membrane. When the cell membrane is healthy, f_c is low. That is, when the function of cell membranes normally works well, f_c becomes low because current flows through the cell membrane even though applying a current having low frequency (<50 kHz, 2.1×10^{-10} eV) to the cell membrane. When the cell membranes are not healthy, f_c moves toward the high frequency. That is, when the function of cell membranes does not work properly, f_c becomes higher because AC cannot penetrate cell membrane although applying AC having a high frequency (>50 kHz) to the cell membrane, which exceeding the threshold energy (2.1×10^{-10} eV). In this study, f_c was 50 kHz for a left forearm and 40 kHz for a right forearm.

The phase angle (Θ), associated with changes in cell membrane integrity and alterations in fluid balance, has been established as a global marker for the diagnosis of malnutrition and clinical prognosis. A higher phase angle means an increase in BCM (muscle mass) or a decrease in fluid, either the recovery from infection and injury or a decrease in fluid from dehydration. A loss of fat could also increase phase angle. On the other hand, a lower phase angle could mean a loss of BCM, or an increase of fluid (rehydrating, or sign of inflammation or infection [19].

Fig. 5 demonstrates the phase angle (Θ) at 19 frequencies, ranging from 5 to 500 kHz. The phase angle was increased from 5 to 50 kHz, and then decreased from 50 to 500 kHz. The phase angle (Θ) was strongly dependent on the applied frequency.

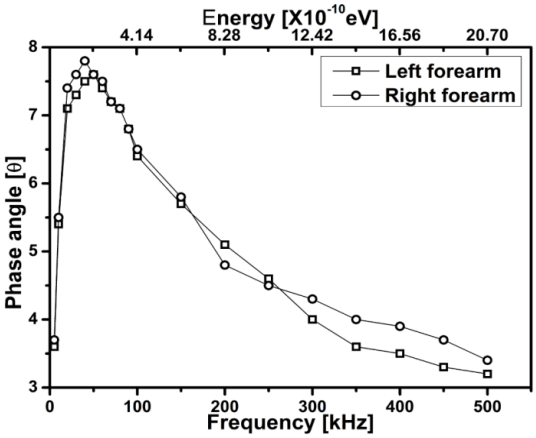

Fig. 5. The measured phase angle (θ) vs. frequency for left and right forearm.

The phase angle at the right forearm was slightly larger than that for the left forearm. The maximum phase angle at a right forearm was 7.8° at 40 kHz, whereas that at a left forearm was 7.6° at 50 kHz. According to Kumar *et al.* [20], the phase angle (Θ) values for healthy males and females were 7.43±0.98° and 7.05±1.1.58°, respectively. Our measured phase angle was higher than that reported by Kumar *et al.* since experimental subjects in this study were young healthy male subjects with high muscle mass. The phase angle () has been suggested to be an indicator of cellular health, where higher values reflect higher cellularity, greater cell membrane integrity and better cell function [18].

4. CONCLUSION

While applying a constant AC of 800 μA to the inner region of forearms, the BI was measured at nineteen frequencies ranging from 5 to 500 kHz using BIMS with multi-frequency. The distance between electrodes attached to forearms was 7 cm. Experimental results were as follows.

First, the BI was measured at nineteen frequencies ranging from 5 to 500 kHz using BIMS. At a frequency of 5 kHz, the BI value was 733.71 Ω at left forearm and 712.70 Ω at right forearm, respectively. The BI was decreased from 5 to 50 kHz and then gradually decreased from 50 to 500 kHz. In addition, the BI at a right forearm was slightly lower than that at a left forearm. This is because eight of ten experimental subjects were right-handed (with higher muscle mass on the right forearm). In addition, the PM was 0.702 at right forearm whereas the PM was 0.708 at left forearm. The resistance (R) and reactance (X_c) were simultaneously obtained as a function of applied frequency. Resistance (R) exhibited a similar behavior as impedance (Z) as a function of frequency. When the applied frequency was lower than threshold (50 kHz), the applied AC could not penetrate the cell membrane so that the current flew through ISF. However, when the frequency was higher than threshold (50 kHz), the applied AC flew through both ECF and ICF. The reactance (X_c) was gradually decreased further when the applied frequency was increased up to 500 kHz.

Second, Cole-Cole diagram (the relationship between resistance and reactance) was obtained for left and right forearm. At very low frequency (~Hz), the BI is only resistive, corresponds to the extracellular resistance, AC cannot flow through the ICF because it cannot penetrate cell membrane capacitance. As the applied frequency increases, the phase angle (Θ) gradually increases because more AC is diverted away from the ECF resistance, and flows through the capacitance of the ICF path. At high frequencies (>500 kHz), the ICF capacitance becomes negligible, so AC enters the parallel resistance of ICF and ECF compartments. The reactance (X_c) of cell membrane is now nil, so the entire bioimpedance again is just resistive and so returns to the resistance axis. The characteristic frequency (f_c) was 50 kHz for a left forearm and 40 kHz for a right forearm.

Third, the phase angle (Θ) was significantly increased from 5 to 50 kHz, and then was gradually reduced from 50 to 500 kHz. The phase angle (Θ) was strongly dependent on the applied frequency.

The phase angle (Θ) at the right forearm was slightly larger than that for the left forearm. The maximum phase angle (Θ) at a right forearm was 7.8° at 40 kHz, whereas that at a left forearm was 7.6° at 50 kHz. This is due to the facts that the majority of subjects is right-handed, with greater muscle mass and better cell membrane integrity in the right forearm.

In this study, BI parameters were acquired for evaluating the physiological function of human forearm using the multi-frequency impedance measurement system. In addition, the pathophysiological function of human tissue could be evaluated using the extracted parameters.

REFERENCES

[1] J.W. Horton and A.C. Ravenswaay, "Electrical Impedance of the Human Body,"*Journal of the Franklin Institute.*, Vol. 20, pp. 557-572, 1935.

[2] A. Thomasset, "Bio-electrical Properties of Tissue Impedance Measurements," *Lyon Medical Journal*, Vol. 207, pp. 107-118, 1962.

[3] B.E. Lingwood, P.B. Colditz, and L.C. Ward, "Methods for the Assessment of Human Body Composition: Traditional and New," *Proceedings of Information Systems Security Association Professional*, Vol. 1, pp. 367-370, 1999.

[4] H.C. Lukaski, Methods for the Assessment of Human Body Composition: Traditional and New," *American Journal of Clinical Nutrition*, Vol. 46, pp. 537-556, 1987.

[5] H.C. Lukaski, "Biological Indexes Considered in the Derivation of the Bioelectrical Impedance Analysis," *American Journal of Clinical Nutrition*, Vol. 64, No. 3, pp. 397-404, 1996.

[6] P. Deurenberg, J.A. Weststrate, and J.G. Hautvast, "Changes in Fat-free Mass During Weight Loss Measured by Bioelectrical Impedance and Densitometry," *American Journal of Clinical Nutrition*, Vol. 49, pp. 33-36, 1989.

[7] R.F. Kushner and D.A. Schoeller, "Estimation of Total Body Water by Bioelectrical Impedance Analysis," *American Journal of Clinical Nutrition*, Vol. 44, pp. 417-424, 1986.

[8] M.R. Scheltinga, D.O. Jacobs, T.D. Kimbrough, and D.W. Wilmore, "Alternations in Body Fluid Content Can Be Detected by Bioelectrical Impedance Analysis," *Journal of Surgical Research*, Vol. 50, pp. 461-468, 1991.

[9] M. Miyatani, H. Kanehisa, and T. Fukunaga, "Validity of Bioelectrical Impedance and Ultrasonography Methods for Estimating the Muscle Volume of the Upper Arm," *European Journal of Applied Physiology*, Vol. 82, pp. 391-396, 2000.

[10] H. Kanai, M. Haeno, and K. Sakamoto, "Validity of Bioelectrical Impedance and Ultrasonography Methods for Estimating the Muscle Volume of the Upper Arm," *European Journal of Applied Physiology*, Vol. 82, pp. 391-396, 2000.

[11] J.H. Kim, S.S. Kim, S.H. Kim, S.W. Baik, and G.R. Jeon, "Comparing the Whole Body Impedance of the Young and the Elderly using BIMS," *Journal of Sensor Science and Technology*, Vol. 25, No.1, pp. 20-26, 2016.

[12] K.S. Cole and R.H. Cole, "Dispersion and Absorption in Dielectrics: I. Alternating Current Characteristics," *Journal of Chemical Physics*, Vol. 9, pp. 341-351, 1936.

[13] J.H. Kim, W.Y. Jang, S.S. Kim, J.M. Son, G. C. Park, Y.J. Kim, et al., "Development of Bioelectric Impedance Measurement System using Multi-Frequency Applying Method," *Journal of Sensor Science and Technology*, Vol. 23, No. 6, pp. 368-376, 2014.

[14] H.C. Lukaski, P.E. Johnson, W.W. Bolonchuk, and G.I. Lykken, "Assessment of Fat-free Mass using Bioelectrical Impedance Measurements of the Human Body," *American*

Journal of Clinical Nutrition, Vol. 41, No. 4, pp. 810- 817, 1985.

[15] Biodat Research Group, http://bio.felk.cvut.cz/biocmsms/index.php?page=body-impedance, (accessed May., 9, 2016).

[16] Bodystat, http://www.bodystat.com/information/prediction-marker, (accessed May., 11, 2016).

[17] London's Grobal University, https://www.ucl.ac.uk/medphys/research/eit/pubs/bioimpedance_overview.pdf, (accessed May., 17, 2016).

[18] K. Norman, N. Stobäus, M. Pirlich, and A. Bosy-Westphal, "Bioelectrical Phase Angle and Impedance Vector Analysis : Clinical Relevance and Applicability of Impedance Parameters," *Journal of Clinical Nutrition,* Vol. 31, pp. 854-861, 2012.

[19] R. Buffa, B. Saragat, S. Cabras, A. C. Rinaldi, and E. Marini, "Accuracy of Specific BIVA for the Assessment of Body Composition in the United States Population," *PLOS One,* Vol. 8, Issue 3, e58533, 2013.

[20] S. Kumar, A Dutt, S. Hemraj, S. Bhat, and B. Manipadybhima, "Phase Angle Measurement in Healthy Human Subjects through Bio-Impedance Analysis," *Iran Journal Basic Medical Sciences*, Vol. 15, No. 6, pp. 1180-1184, 2012.

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