Analysis of Regression Equation for Skeletal Muscle Mass using Bioimpedance Technique

Divya Subramanian, Chaitali S Nachane, Jyothi S Warrier, Sadhana A Mandlik

Abstract— Determination of skeletal muscle mass in the body helps to analyze the associated loss of strength in individuals. It can be used in the study and analysis of sarcopenia and sarcopenic obesity which is now a global health problem. Although Computed Tomography, Magnetic Resonance Imaging and Dual Energy X-ray Absorptiometry can be used for the estimation they are expensive and the individual is subjected to small radiation exposure. The present study uses Bioelectrical Impedance method for estimation of Skeletal Muscle Mass using regression equations. 126 Indian subjects (age: 38±9 years) are measured for Skeletal Muscle Mass using the commercial body composition analyzer and validated against the developed Bioelectrical Impedance Measurement system. The results of the study show that there is a high degree of correlation and small error between these two methods.

Index Terms— Bioelectrical Impedance Analysis, Body Composition Anlyzer, Skeletal Muscle Mass, Sarcopenia, Impedance.

1 INTRODUCTION

Skeletal Muscle Mass (SMM) is associated with strength in the body. Determination of skeletal muscle mass helps to analyze sarcopenia and sarcopenic obesity in individuals. SMM forms the largest proportion of fat free mass as it is a tissue rich in electrolytes. Skeletal muscle comprises about 40% of body mass and plays vital role in regulating metabolism, notably via insulin regulated glucose uptake, maintaining posture and controlling movement [1]. Over one fifth of the body mass in the newborn consists of skeletal muscle tissue and relative amount in the average adult male approaches almost one half of the body weight. There are around 600 discrete skeletal muscles in humans and each has a definable set of components. The components of the muscle can be characterized in terms of Cellular, molecular and Atomic level components. Before puberty muscles of the lower limb grow in proportion to the body weight. Muscles in the upper body grow less rapidly, muscles maintaining the same proportion as long bones increase in length. During puberty and adolescent growth spurt, skeletal muscles grow more rapidly in relation to height and body weight. [2] Significant reductions in the quantity and quality of skeletal muscles increase the risk of diseases including diabetes and heart disease.

Maintenance of SMM is tightly regulated by processes controlling muscle protein synthesis and muscle protein breakdown and experiences hypertrophy or atrophy in response to altered functional demands. Triggered by extracellular signals such as growth factors and mechanical overloading, muscle can increase in mass by changing the overall dimensions of its fibers. On the other hand, immobilization, clinical application of corticosteroids, cachexia and normal aging processes, skeletal muscles undergo significant loss of mass [3]. Aging is associated with a loss in muscle mass and strength with excessive loss leading to sarcopenia. Presence of sarcopenia is a predictor of poor gait, balance, falls and fractures. Sarcopenic obesity is a condition in which high levels of body fat co-exist with muscle loss and sarcopenia usually found in the elderly. Sarcopenia is also called as muscle wasting or muscle loss is an age related process associated with functional impairment. Age related changes in molecular signaling proteins contributes to the inability to maintain SMM as we age. Causes of sarcopenia are can include disuse, changing endocrine function, chronic diseases, inflammation, insulin resistance and nutritional deficiencies.

The loss of muscle mass and strength is attributed to progressive atrophy, loss of individual muscle fibers with some loss of motor units and loss of muscle quality due to infiltration of fat and other non contractile tissue. Considered to be a neuromuscular syndrome, loss of muscle strength can be slowed by physical training and good nutrition. There can also be a cancer related loss of muscle mass which is referred to as Cachexia. Abnormalities associated with cancer cachexia include anorexia, weight loss, muscle loss and atrophy and associated alterations in carbohydrate, protein and lipid metabolism. While proinflammatory cytokines, hypermetabolism and malnutrition play an important role in cachexia, hormonal changes and physical inactivity are main triggering factors in sarcopenia [1]. Thus estimation of SMM is useful in body composition studies.

The present study uses Bioelectrical Impedance analysis (BIA) for estimation of SMM. BIA measures the impedance of body issues in response to a small alternating current (less than 1mA). The use of BIA is based on the principle that the conductivity of an electrical impulse is greater through fat-free tissue than it is through fatty tissue. Through electrodes on the hand and foot, the instrument measures a small electrical current passing between the electrodes and therefore the body's impedance (resistance) to the electrical current. Depending on whether there is more fatty or fat-free tissue, the flow of the current will be different. If more fat tissue is present, the slow-

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er the conductance, while more muscle will cause it to be faster.

In our experiment we adopted the tetrapolar BIA technique, which involves injecting constant amplitude currents at two frequencies (50, 6.25 KHz) through two electrodes and measuring the voltage from other two electrodes. This technique circumvents the error of inadvertent inclusion of electrode impedance. The accuracy of the measurements thus made is dependent on the electrode position and proper estimation of the height and weight of the subjects. This has to be validated with a reference.

The purpose of this research study is to develop and validate the developed equation using the Body Composition Analyzer (BCA) developed at Bhabha Atomic Research Center (BARC, Mumbai) against InBody 720 (Biospace, Korea). InBody 720 shows the impedance values from the measurements at a diverse range of frequencies from 1KHz to 1MHz and is the first version to use the reactance method. It uses 8 point tactile electrode method. InBody 720 has been validated with Dual Energy X-ray Absorptiometry (DEXA) for Bone Mineral Content [4].

2 METHODS

The study group consisted of 126 Indian nationals (62 females and 64 males) between 19 and 60 years of age (38±9 years). The heights of all the individuals were estimated nearest to 1cm. They were informed about the study protocol and procedures. Data was collected before eating or 2 hours postprandial. These were used for formation of the regression equations using the Minitab Software.

The measurements for SMM was first obtained from the commercial instrument InBody 720 (Biospace, Korea) which automatically makes measurements at frequencies of 1, 5, 50, 250, 500 KHz and 1MHz incrementally. The applied current rating is 400 µA at higher frequencies. The subjects are instructed to remove watches or any other metallic objects as they may interfere with the measurements. Subjects are asked to place their feet and heel on the 2 metallic electrodes at the base of the instrument and palm and thumb on the handrails of the metallic grip electrodes. The hand is fully extended at 15° from the trunk and the subject is requested not to move during the acquisition.

For measurements using BCA (BARC, Mumbai) tetrapolar whole body BIA is used. Data is collected with subjects sitting on a chair and arms abducted to avoid touching of the trunk. They are asked to place their feet on the shoes to prevent ground contact. The two current injected electrodes are placed on the right palm and foot and the voltage measuring electrodes are placed on the right wrist and ankle. The electrodes used are braided copper wire electrodes (silver plated).
The values of the two impedances can be viewed in the user interface panel created at BARC Mumbai as shown in Figure 1(Name erased).

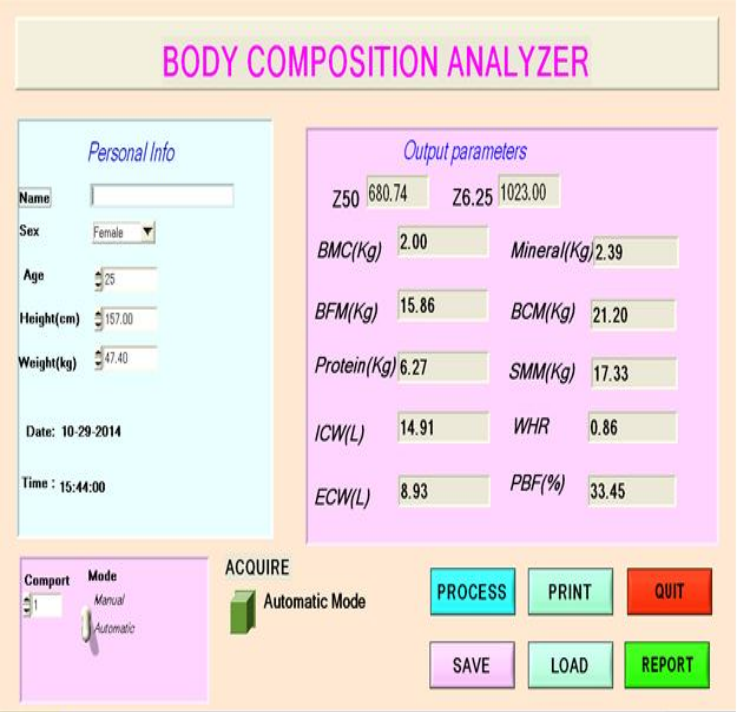

Fig.1. User Interface Panel (BARC,Mumbai) showing SMM.

The impedances and the corresponding calculated values of different parameters including SMM will be displayed. The Save button is used to save the data in a PSpice Circuit File which can be loaded at a later time using the Load button. To exit from the User Interface, the Quit button is pressed. The comport is specified for serial communication using RS232.

Figure 2 shows the block diagram of the system used in the study. The Bio-Medical Instrumentation Processor Board (BMIPB) generates a square wave of 50KHz. A frequency of 6.25KHz is derived through the synchronous up / down counter. These two square wave frequencies are converted into pure sinusoidal alternating signals using a series of second order low pass and narrow bandpass filters. Selecting either one of the frequencies using the multiplexer, it is passed through the V-I Converter using the isolation transformer and fed to the patient. The sensed voltages are amplified using instrumentation amplifier and rectified and filtered to produce a pure DC voltage, proportional to the impedances of the subject under investigation. This is given to the ADC of the BMIPB and displayed on the user interface panel.

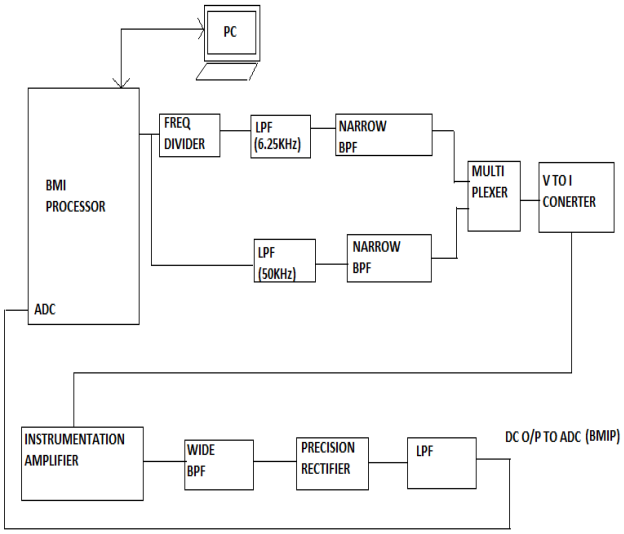

Fig.2. Block Diagram implementation of BCA (BARC,Mumbai).

Table 1 shows the anthropometric characteristics of the 126 subjects included in the study for developing the regression equations. Data of 26 subjects was collected to validate the developed equation and the Correlation and Bland Altman plots are plotted for the same.

TABLE 1
ANTHROMOPETRIC CHARACTERISTICS OF STUDY GROUP
(126 SUBJECTS)

Gender	Parameters		
	Age	Weight	Height
Men	37.25±9.34	71.06±11.05	166.66±6.74
Women	38.56±9.47	60.59±9.20	155.72±5.91
Combined	37.89±9.39	65.91±11.42	161.28±8.37

3 RESULTS

A total of 126 individuals were subjected to the study. Stepwise regression was performed using Minitab for formation of the prediction equation for SMM with R-sq adj=99.97 and S=0.0894. The prediction equation for SMM is:

$$SMM = -1.707 + 2.79 \times \Pr otein + 0.1 \times ICW \quad (1)$$

Where SMM is in Kg and ICW represents Intracellular water and both ICW and Protein are estimated by BCA(BARC, Mumbai). The equation is validated with data collected from 26 subjects, different from those used initially in the study. Figure 3 shows the Scatter plot between BIA equation and the commercial instrument InBody 720. Figure 4 shows the Bland Altman Plot for the 26 subjects.

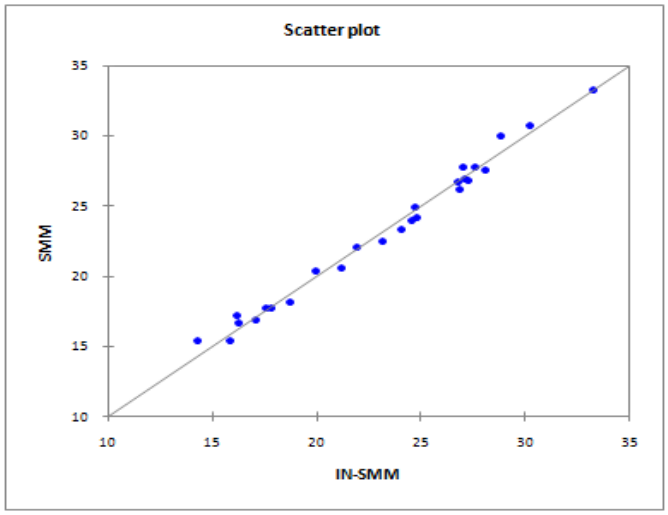

Fig.3.Scatter plot showing correlation between IN-SMM and SMM. IN-SMM represents the SMM values obtained from InBody-720 and SMM represents the SMM values obtained from BCA.

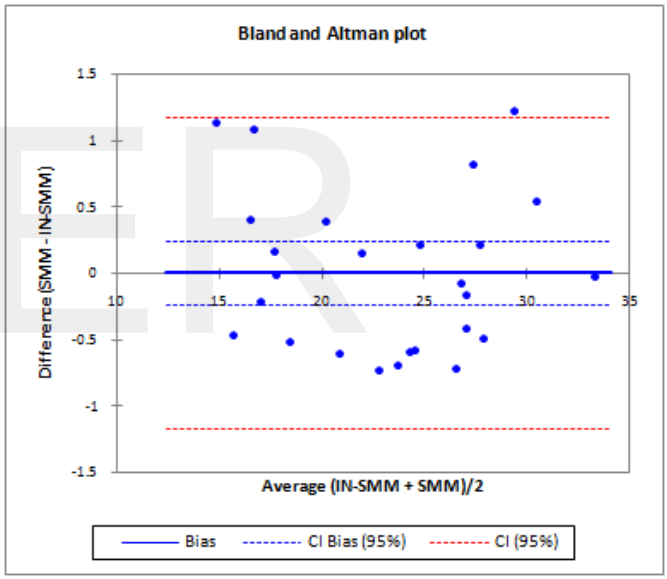

Fig.4.Bland Altman plot for SMM. IN-SMM represents the SMM values obtained from InBody720 and SMM represents the SMM values obtained from BCA. X axis represents the Average and Y axis represents the Difference.

4 CONCLUSION

Thus BIA can be used as a safe and simple technique for estimation of SMM. It poses an advantage of non exposure to radiation as compared to the presently available techniques.

Various body composition studies indicate that there can be an increase in Skeletal Muscle Mass and non adipose tissue components with a certain increase in adipose tissue components. A possible explanation for this is that obesity places a greater load on skeletal muscles imparting a training effect increasing the muscle mass and strength. However not all obese individuals have increased muscle mass. 5-10% of elderly are both obese and have low content of muscle mass, a condition of sarcopenic obesity posing a greater risk of disability and mortality [5].

Maintaining SMM and function throughout life is a pre requisite for good health and independent living. While skeletal muscles have an ability for self renewal and regeneration, its capacity to perform these tasks decline with age. Thus SMM is an important parameter which is being estimated using BIA technique.

The results of the analysis show a high degree of correlation among the two methods and small error. The impedance of different individuals vary according to various factors like height, weight, water and fat content in the body. The accuracy of the system can be increased by closer estimation of height and weight to the nearest centimeter and Kilogram respectively. Placement of electrodes also tends to affect the accuracy. The study cannot be performed with individuals having leg or foot amputations, pacemakers or implanted medical devices.

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REFERENCES

[1] Gordon. S Lynch, *Sarcopenia-Age related Muscle wasting and weakness: Mechanisms and treatments*. New York: Springer Science+ Business Media B.V, pp. 207-208, 2011.

[2] Victor Preedy, Timothy Peters, *Skeletal Muscle Pathology, Diagnosis and management of Disease*. San Francisco: Greenwich Medical Media,2002, pp:429-432.

[3] Hao Shi P.H.D, *Modulation of Skeletal Muscle Fiber Growth and Specialization by Mitogen Activated Protein Kinase Pathways*, Ann Arbor: Purdue University, 2007, pp:147.

[4] B.R Patil, D.P Patkar, S.A Mandlik, M.M Kuswarkar, G.DJindal, "Single Prediction equation for bioelectrical Impedance Analysis in adults aged 22-59 years," *Journal of Medical Engineering and Technology,* Vol. 35*, No. 2,*pp.109-114, February 2011, doi:10.3109 / 03091902.2010.543751.

[5] Jeffrey J Brault, G Lynis Dohm and Joseph A Houmard, *Handbook Of Obesity Epidemiology*, *Etiology and Physiopathology,* Third edition., Vol. 1. Florida: CRC press, , 2014, pp:249-250.

[6] Joseph.D.Bronzino, *The Biomedical Engineering Handbook, Medical devices and systems,*Third edition. Florida: CRC Press, 2006, pp(53-1)-(53-3).

[7] Timothy J. Doherty, "The influence of aging and sex on skeletal muscle mass and strength," *Current Opinion in Clinical Nutrition and Metabolic Care*, 4:pp503-508, 2001.

[8] Victor R.Preedy, *Handbook of Anthropometry, Physical Measures of Human Form in Health and Disease*, Volume 1 parts 1-6. New York: Springer,2012,pp: 377.

[9] Sami F. Khalil, Mas. S. Mohktar and Fatimah Ibrahim, "The Theory and Fundamentals of Bioimpedance Analysis in Clinical Status Monitoring and Diagnosis of Diseases,"*Sensors*, pp. 10895-10928, June 2014, doi:10.3390 / s140610895.