Development of Regression Equation for the Measurement of Visceral Fat Area using Bioimpedance Technique

ABSTRACT

Visceral fat is a predictor of obesity, metabolic syndrome and type II diabetes. The presently available technique, Computed tomography (CT) causes radiation exposure and is expensive. Abdominal obesity is a well established risk factor for obesity. There tends to be a risk of development of type 2 diabetes in obese individuals with abdominal obesity and insulin resistance. Abdominal obesity includes both subcutaneous and intra abdominal (visceral) adipose tissue and is associated with an increased risk of coronary heart disease (CHD) morbidity. A positive correlation between visceral fat, insulin levels and homeostasis model assessment insulin resistance index (HOMA-IR) in both genders was verified \( r = 0.522 \) in boys and \( r = 0.309 \) in girls.

The study aims at developing a bioelectrical impedance based system for visceral fat area. The visceral fat area of 126 subjects (age: 38 ± 9 years) was first measured using the commercial instrument InBody 720 (Biospace, Korea) and then using the body composition analyzer (BCA) Bhabha Atomic Research Centre (BARC, Mumbai). Tetrapolar bioelectric impedance analysis (BIA) using two frequencies (50 KHz and 6.25 KHz) was used to develop the regression equation as follows: VFA = \([-142 + 187^*whr + 1.94^*weight -1.35^*Zbody 50 \Omega) + 1.027^*age (years) -0.97^*height (cm) + 7.2^*sex -1.40^*Zbody 50/W (\Omega Kg^{-1})]\ cm^2. Sex = 0 for women and 1 for men (with R-sq adj = 96.87 and S = 5.37).

The equation thus developed using BCA (BARC, Mumbai), validated with 60 subjects shows that there exists a high degree of correlation (R-sq adj = 96.87) between the two techniques.

Keywords: Bioelectrical impedance analysis, Biomedical instrumentation processor, Body composition analyzer, Visceral fat.

by the manufacturer. These frequencies are introduced into the body and the applied current ratings are 90 µA at 1 KHz and 400 µA at other frequencies. The product has been designed, manufactured and inspected under the full quality assurance of Biospace and fulfils the standards of IEC60601-1 and IEC 60601-2. The entire measurement takes around 5 to 6 minutes. The subjects are instructed to remove the watches and any other metallic objects. Subjects were asked to place their feet and heel on the two metallic electrodes provided at the base of the instrument and the palm and thumb on the handrails of the metallic grip electrodes. During the data acquisition it is required that the subjects do not flex and stand comfortably. The arms are required to be fully extended and at an angle of 15° from the trunk.

For measurements using BCA (BARC, Mumbai) the impedances at 50 and 6.25 KHz was measured for all the subjects. The instrument uses a whole body BIA approach. The subjects were asked to sit on a chair with their arms abducted to avoid touching the sides. Tetrapolar configuration was used in which braided copper wire electrodes (silver plated) were placed at the arm and foot. For both the programmed frequencies, an alternating current of less than 1 mA root means square is introduced into the body. The current injecting electrodes are placed on the palm and foot and voltage sensing electrodes are placed in the wrist and ankle. The right palm and foot were chosen as the electrode placement sites.

The values of the two impedances can be viewed at the user interface panel and the other already developed parameters will be displayed. The schematic block diagram used in the analysis is shown in Flow Chart 1. The biomedical instrumentation processor board (BMIPB) is used to initiate a communication between the PC and the developed system. The UART input clock is 36 MHz and by default serial port is set to 19200 baud. The entire system works at + 5V dc.

The BMI processor generates a square wave frequency of 50 KHz which is also given to a synchronous up/down counter. The synchronous up/down counter generates the second frequency of 6.25 KHz used in the design. Both the frequencies are then converted into pure sinusoidal alternating signals using a series of second order low pass filters and narrow band pass filters. The multiplexer selects any one frequency at a time. The selected frequency is passed through a V-I converter and fed to the patient through the isolation transformer. Through the voltage sensing electrodes, the developed voltage is amplified using a precision instrumentation amplifier and passed through a wide band pass filter to remove the superimposed noise and produce a pure sinusoidal alternating signal. Further, this output is also rectified and filtered to produce a pure DC voltage which is proportional to the impedance of the subject under investigation. This value is given to the ADC of the BMIPB and displayed on the user interface panel.

Using the impedances calculated at the 2 frequencies, additional BIA parameters like $Z_{body\ 50/6.25}/h$, $h^2/Z_{body\ 50/6.25}$, $w^2/Z_{body\ 50/6.25}$ were calculated. Stepwise regression was used to develop an equation for VFA. The level of significance was set at 0.15. All p-values less than 0.15 are considered. The BIA parameters with highest degree of correlation and least error were considered. The level of significance is the default value set by Minitab. Choosing a lesser value performs lesser steps in the stepwise regression analysis. Although selection of 0.05 level of significance yields the same results, the default value has been retained. The equation was developed and

Flow Chart 1: The body composition analyzer (BARC, Mumbai)
validated against a sample of 60 subjects. The correlation graphs and Bland Altman Plots were plotted.

This study cannot be performed with individuals having foot or leg amputations, pacemakers or implanted medical devices as it may cause the devices to malfunction.

RESULTS

A total of 126 individuals were subjected to this study. The anthropometric parameters of all the subjects are shown in Table 1. Stepwise regression was used for formation of the prediction equation shown below (with $R^2_{\text{adj}} = 96.87$ and $S = 5.37$). Figure 1 shows the correlation between BIA equation and the commercial instrument InBody 720 and Figure 2 shows the Bland Altman plots which was validated with a study group of 60 subjects. The Bland Altman plot shows a bias of –0.176 denoted by the dark blue line. The bias denotes the mean difference between the commercial instrument InBody 720 and the developed BIA equation indicating the tendency to deviate from the true value.

The dashed blue lines indicate the 95% confidence interval of the bias.

The dashed red lines indicate the limits of agreement at $\pm 2 \text{ SD}$ showing that VFA measured using the BIA equations will vary between +20.619 and –20.971.

The predicted equation for VFA is given as:

$$\text{Visceral fat area} = \left[ -142 + 187 \times \text{whr} + 1.94 \times \text{weight (kg)} + 0.135 \times Z_{\text{body 50}} (\Omega) + 1.027 \times \text{age (years)} -0.97 \times \text{height (cm)} + 7.2 \times \text{sex} -1.40 \times Z_{\text{body 50/W}} (\Omega \text{kg}^{-1}) \right] \text{cm}^2; \text{Sex} = 0 \text{ for women and 1 for men.}$$

Table 2 shows the stepwise regression performed with the software minitab. The constant has to be included in the equation. The first row of each predictor indicates the constant or the contribution of each predictor and has to be multiplied with each predictor. The t-value compares the means of the estimated and standard values. p-value determines the appropriateness of rejecting the parameter in the equation. All p-values in this case are 0.000 < 0.15 and hence are accepted.

S denotes the standard error of the regression. R-sq ($R^2$) denotes the squared value of validity coefficient and R-sq (adj) is adjusted R-sq. The adjustment is important because the $R^2$ for any model will increase when a new term is added.

DISCUSSION

Studies have shown the relationship between obesity and several diseases in adult life, such as arterial hypertension, type 2 diabetes mellitus, cancer, and also cardiovascular mortality, body fat excess, mainly in the form of central obesity, is closely correlated with these diseases, mainly with nonalcoholic fatty liver disease (NAFLD). There is evidence to suggest that visceral adiposity is more influential than body mass in predicting fatty liver disease. Abdominal obesity itself was found to be independently associated with an increased risk of coronary heart disease (CHD).

Deposition of fat into ectopic areas depends on total body fat mass and an individual’s basic susceptibility that is in turn related to age, gender, and ethnicity. Gender and ethnicity were found to influence group differences in visceral adiposity.
Fat accumulation in the abdominal cavity increases intraabdominal pressure. The increase of intra-abdominal pressure observed in visceral obesity is able to pump upwards the diaphragmatic muscle, compressing the parenchyma of the lung, particularly at the basal regions. Moreover, the over-stretching of the diaphragmatic muscle fibers caused by the elevation of the diaphragmatic domes produced by visceral fat can decrease the contractile efficiency of the diaphragmatic muscle.5

Bioelectrical impedance analysis is a simple, noninvasive and cost effective technique to evaluate Visceral Fat Area. Bioimpedance refers to the electrical properties of a biological tissue, measured when current flows through it. In bioimpedance measurements, a current magnitude, about 800 μA, is chosen to be small enough so as not to be perceived by the subject, but large enough to produce voltages that are above interfering "noise."6 It has the advantage of non exposure to radiation and ease of follow-up as compared to CT or DXA (Dual Energy X-ray absorptiometry).

The study shows that waist to hip ratio (WHR) acts as a positive predictor for visceral fat. Higher the WHR, higher is the visceral fat and vice versa. Visceral fat area at or below 100 cm² is considered normal whereas above 160 cm² is associated with high risk. It is also seen that higher the BMI higher is the value of VFA.

Regression analysis involves estimating statistical relationships between response variables and two or more predictor variables. In our study, regression equation for VFA is estimated. Minitab is software that assists in the analysis of data that is collected.

The commercial instrument InBody 720 uses segmental BIA approach showing impedance values for right arm, left arm, trunk, right leg, and left leg. For validation of commercial instrument InBody 720, Bone Mineral content of 22 healthy subjects was measured by InBody 720 and DEXA. High correlation (R = 0.9531) and low error (total error = 0.0913 kg) was found between these two methods.7 The BCA developed uses full body BIA approach. The accuracy of the system can be improved by carefully measuring the height and through proper placement of the electrodes.

CONCLUSION

Bioelectric impedance analysis can be considered as a potential technology for measurement of different body composition parameters. Visceral fat area is one of the important parameters that can be determined by the instrument. The results of the analysis show that although there is a high degree of correlation between InBody 720 and the instrument developed, the standard error of regression (S = 5.37) remains high. Since Visceral fat is a deep seated fat located below the muscles, it would require higher frequencies for penetration. Use of frequencies in the range of 250 KHz would produce accurate results. The future implementation of the above said system will reduce the error and help in accurately determine VFA using BIA. The impedances for different individuals vary according to various factors like height, body weight, fat, and water in the body.

The analysis was carried out using Stepwise regression. Standard stepwise regression both adds and removes predictors as needed for each step. Minitab stops when all variables not in the model have pvalues that are greater than the specified alpha-to-enter value and when all variables in the model have pvalues that are less than or equal to the specified alpha-to-remove value. The shortcomings of stepwise regression are that if two predictor variables are highly correlated, only one might end up in the model even though either may be important. Stepwise regression might not always stop with the model with the highest R² value possible for a specified number of predictors.

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REFERENCES


