Measurement of Visceral Fat Using Bio-Impedance Analysis

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Abstract—Visceral fat is intra-abdominal fat stored around a number of important internal organs such as the liver, pancreas and intestines. A battery operated system is proposed in the paper for the estimation of visceral fat. Estimation of visceral fat is based on principle of bio-impedance where small alternating current (below 1 mA) of constant amplitude and high frequency of 250 kHz, 50 kHz and 6.25 kHz are injected into the body through a pair of current electrodes and the voltage is picked up using through a pair of sensing electrode. Bio-impedance analysis technique measures body impedance from the subjects. Electrodes are placed in tetrapolar configuration. Bio-impedance analysis (BIA) is a noninvasive, low cost and a commonly used approach for body composition measurements. Estimating visceral fat can be useful for diagnosis of type 2 diabetes (high blood glucose level), heart disease, cancer etc. The purpose of this study is to validate BIA equation for estimation of visceral fat area (VFA) against commercialized instrument In-Body 720 (Biospace, Korea).

Index Terms— Bioimpedance analysis, Body composition, Clinical status monitoring, Diseases, Estimation, Visceral fat, Tetrapolar electrode configuration

1 Introduction

BODY composition analysis refers to the estimation of different body constituents. A healthy body composition is one that includes a lower proportion of body fat and a higher proportion of fat free mass [1]. People of same sex and body weight look completely different from each other because they have a different body composition. Fat is an essential part of the body. Essential fat in men is 2-5% and in women is 10-13%. It provides energy, maintain body temperature and insulate the body. The fat we feel just under the skin is subcutaneous fat but the extra fat which is stored within abdomen where organ reside is visceral fat. Visceral fat is an intra-abdominal fat. Health risk associated with visceral fat is type 2 diabetes, heart disease, breast cancer, colorectal cancer etc. The method which is used for measurement of visceral fat area is bio-impedance analysis (BIA). The bilipid cell membrane divides the extra and intracellular media. The impedance of biological tissue comprises two components, the resistance and reactance (capacitive). At zero (or low) frequency, the capacitive reactance is infinite and the current does not penetrate the cell membrane, which acts as an insulator (open circuit), and therefore the current passes through the extracellular fluid only. Thus the total body impedance reflects only extracellular fluid. At infinite frequency (or very high frequency) the capacitive reactance is almost negligible, it acts as a short circuit and total body impedance reflects the combination of both intracellular and extracellular fluid. Principle of BIA is based on injecting small alternating current (below 1 mA) of constant amplitude and different frequencies of 250 kHz, 50 kHz and 6.25 kHz into the body through a pair of current electrodes and the voltage is picked up using another pair of sensing electrode. The frequencies used for estimation of visceral fat area are 250 kHz, 50 kHz and 6.25 kHz. Measuring visceral fat is useful in monitoring weight management, nutritional assessment, athletic performance etc. The system is battery operated thus making it advantageous over other methods as it is handheld device, safe, low cost, portable, rapid, easy to perform, and requires minimal operator training. It can be widely used in hospitals, health and fitness centers.

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2 System Configuration

2.1 Block Diagram

The Block diagram (Fig.1.) comprises of the following module mentioned below:

- Battery operated power supply
- Regulator
- DC-DC Converter,
- Microcontroller,
- Low pass and band pass filter
- Multiplexer
- Howland circuit
- Signal conditioning unit
- Serial communication (Bluetooth)
- PC

2.2 Module Description

System consists of a rechargeable DC battery of 8.4 V, 2800 mAh; followed by a regulator IC which supplies + 5V DC. Then it is given to the DC to DC converter which supplies ± 5V to the entire system. Further this + 5V DC is converted into + 3.3V with another regulator IC which is fed to the microcontroller. Microcontroller generates three input signal which are square wave of frequency 250 kHz, 50 kHz and 6.25 kHz respectively. Then square wave is converted into desired sine wave with the help of second order low pass filter and a band pass filter. These signals are then multiplexed with the help of analog multiplexer and selected signal is transmitted at the output of multiplexer by the operator through user interface

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panel. Multiplexer output is then applied to the howland circuit which produces sinusoidal constant current. Then it is injected into the body with the help of current electrodes C1 and C2 which are placed on palm and toe region. The voltage

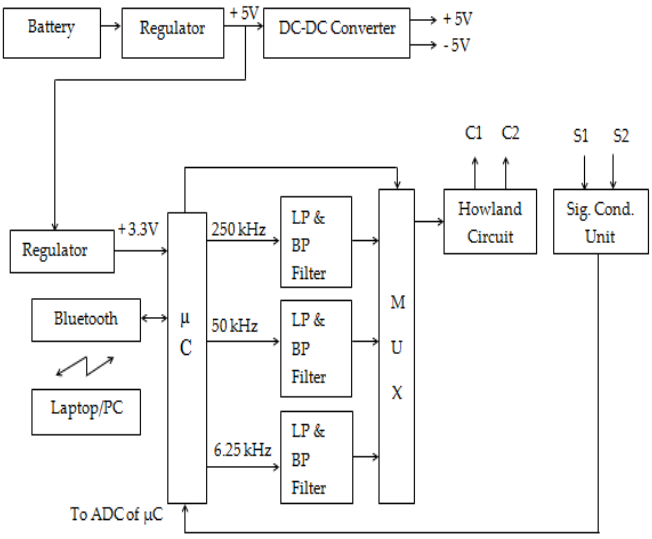

Fig.1. Block diagram for visceral fat measurement.

signal developed along the current path is sensed with the help of sensing electrodes S1 and S2 which are placed on wrist and above the ankle. Then signal is further processed through signal conditioning unit and its analog output is given to ADC of microcontroller. Signal is read by the microcontroller and transmitted to personal computer through bluetooth.

3 Subjects and Methods

3.1 Subjects

The study group composed of 62 subjects in the age group of 20 to 60 years. All subjects were born in India and resided in Mumbai. The subjects were healthy. Before the measurements subjects were kept fasting for nearly 2 hours. The purpose of the study was explained to all the subjects. Each subject was measured by two methods: BIA device developed in house for which equation is predicted for VFA measurement and commercially available segmental multifrequency BIA instrument (Inbody 720, Biospace Co. Ltd. Seoul, Korea) which has been used as a reference.

3.2 Methods

BIA device provides the bioelectrical parameters at various frequencies using tetra-polar electrode configuration. It is based on the tetrapolar bioelectrical impedance measurement approach and operated at frequencies of 250, 50 and 6.25 kHz which are generated by the microcontroller and injected into the body in ascending order of frequency. This device uses limb clamp electrodes for measurement.

Current electrodes C1 and C2 which are placed on palm and toe region and sensing electrodes S1 and S2 which are placed on wrist and above the ankle. Fig.2. shows the tetrapolar electrode positions on the body. Precautions were taken before measurements such as all metal accessories were removed; fasting state (at least for 2 hours) was adhered. The instrument gave the impedance value at three frequencies (250, 50, 6.25 kHz).

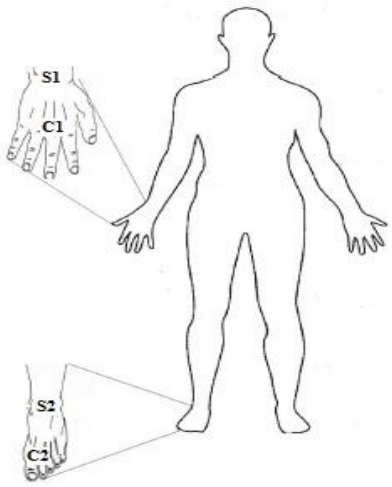

Fig.2. Tetrapolar electrode positions on the body for BIA device where C1 & C2 are current electrodes and S1 & S2 are sensing electrodes.

The measurement was carried out in 62 subjects (43 males and 19 females) in the age group of 20 to 60 years using both the systems. Inbody 720 yielded the predictable variable (VFA) and BIA gave the response variables namely height, weight, age, sex, Z_{body50} , $h^2 / Z_{body250}$, $h^2 / Z_{body6.25}$, hc, hhtr, ahr. This data was used to develop multivariant regression equation, using 'R' which is a free software for statistical computing (open source), given in Table-1. Subsequently measurements were carried at in 30 subjects. Inbody gave the reference values of VFA and BIA gave the observed values of VFA as given in Table-2.

3.3 Statistics

The impedance of the body (Z_{body}) is derived at frequencies 250, 50 and 6.25 kHz. The physical parameters comprise of weight (w), height (h), sex, age, hip circumference, abdominal to hip ratio and hip to height ratio. By combining physical and bioelectrical parameters, the new parameters (h^2/Z_{body}) is derived at 250, 50 and 6.25 kHz frequencies. With the help of statistical software, stepwise multiple regression analysis for BIA prediction equation for VFA is derived. It reads the variable values and implements the predefined algorithm as per selected calculation and analysis. The multiple regression model assumes that a linear relationship exists between some variable Y, which is the dependent variable, and k independent variables, X1, X2,……,X_k. The dependent variables are referred to as response variables and independent variables are referred to as predictor variables. Correlation analysis, on the

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other hand, is concerned with measuring the strength of the relationship between variables. The correlation coefficient 'R' and the coefficient of determination 'R^2' determine how well the regression equation truly represents set of data. A correlation greater than 0.8 is generally described as strong whereas a correlation less than 0.5 is generally described as weak [10]. Statistics calculated for BIA predicted equation for VFA and observed VFA from commercial instrument Inbody720 is expressed as mean ± standard deviation (SD). Table-1 gives the output of software on data from 62 subjects in the form of regression equation.

4 RESULT

A total of 30 healthy adults aged 20 to 60 years were taken for validating the regression equation developed as in Table-1. Table-2 shows the VFA predicted by BIA device and reference VFA by Inbody 720.

TABLE 1
Bioelectrical impedance analysis prediction equation for visceral fat area using all subjects (n=62)

$$VFA = 109.62 - (1.63 \times height) + (2.53 \times weight) + (1.29 \times age) - (4.15 \times sex) + (0.02 \times Z_{body50}) + (2.23 \times \frac{h^2}{Z_{body250}}) - (2.92 \times \frac{h^2}{Z_{body6.25}}) + (1.41 \times hc) - (185.91 \times hhtr) + (53.96 \times ahr).$$

VFA observed by commercial instrument Inbody-720 = 113.1 ±35.3 sq. cm

VFA predicted with BIA equation = 113.0 ± 34.9 sq.cm
($R = 0.9834$, $R^2 = 0.9672$)

n = number of subjects, VFA = visceral fat area, BIA = bioelectrical impedance analysis, h = height (in cms), $Z_{body250}$ = body impedance at 250 kHz, sex: female = 1, male = 0, Z_{body50} =body impedance at 50 kHz, $Z_{body6.25}$ = body impedance at 6.25 kHz, hhtr = hip to height ratio, hc = hip circumference, ahr = abdominal to hip ratio, R = correlation coefficient, R^2 = coefficient of determination.

TABLE 2
VALIDATING VFA BY COMMERCIAL INSTRUMENT INBODY720 VS BIA PREDICTED EQUATION FOR VFA

n	H (cm)	W (kg)	Age (yrs.)	Sex	Inbody VFA (sq.cm)	BIA VFA (sq.cm)
1	159	78.2	25	1	124.2	116.5
2	170.8	79	46	0	107.4	116.8
3	150.2	38.6	35	1	56.3	56.4
4	159.2	77.4	59	1	164.8	164.7
5	164.2	75.4	41	0	129.6	123.1
6	170.5	87.5	35	0	121.4	125.8
7	169	85.6	48	0	153.4	149.3
8	176.8	88.1	25	0	105.4	107.5
9	168.5	66.4	54	0	118.5	116.3
10	173	85.2	22	0	101.1	99.0
11	169.7	76.1	48	0	122.9	122.9
12	172.7	106.3	32	0	165.4	174.1
13	167.5	71.6	38	0	104.2	107.0
14	152.5	68.8	45	1	130.3	126.0
15	183.5	63.9	44	0	40.2	58.4
16	169.5	70	30	0	89.9	79.4
17	161.5	70	59	0	144.4	138.5
18	156	58.4	25	1	70	70.4
19	159.5	63.2	54	0	127.4	121.7
20	169	77.1	28	0	104.7	99.5
21	175.4	82.8	47	0	112.5	123.7
22	164.1	60.9	32	0	75	74.8
23	150.5	46.8	26	1	49.8	48.1
24	144.6	82.4	52	1	169.6	173.9
25	153.1	68.2	52	1	147	138.3
26	169.9	68.8	48	0	104.1	110.3
27	164	64.6	40	1	93	92.1
28	142.5	75.6	58	1	164.1	166.2
29	156.5	49.7	35	1	63.5	58.2
30	153.2	77.9	38	1	134.3	130.2

n = number of subjects, H = height (in cms), W = weight, VFA = visceral fat area, Sex: female = 1 and male = 0.

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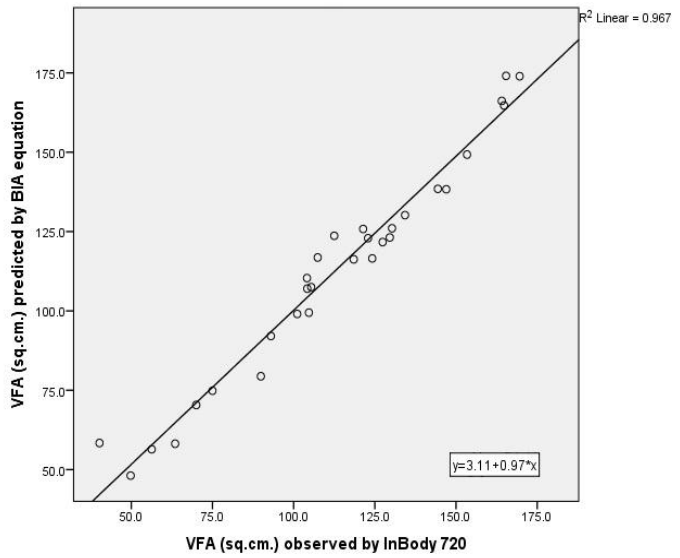

Fig.3.Correlations of visceral fat area (VFA) in all subjects measured by Inbody 720 and predicted by BIA equation.

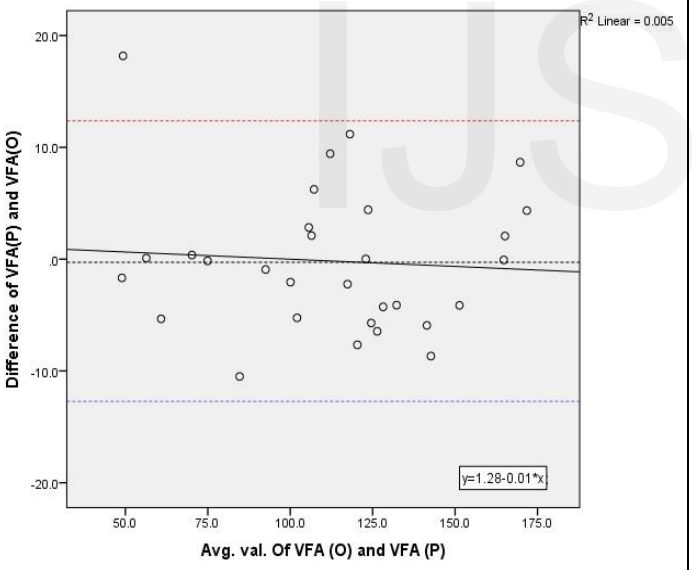

Fig.4. Bland Altman (B&A) plot representing the relation between mean differences in VFA (VFA by BIA- VFA by Inbody 720) and average VFA ([VFA by Inbody 720 + VFA by BIA]/2).

Figure 3 and 4 shows the correlation between VFA observed and VFA reference with the help of scatter plot and Bland-Altman plot. As can be seen from figure 3, there is a correlation of 0.967 between the two values, which validates the regression equation developed. Figure 4 shows that there is a bias of -0.2 in the measurement. This is the overall very slight underestimation by the BIA device developed. Also there is overestimation for lower values of VFA and underestimation for higher values of VFA as revealed by the plot in figure 4.

5 Conclusion

The results shows that the BIA predicted equation validated against commercial instrument Inbody 720 can be used to predict visceral fat area in subjects aged 20 to 60 years. Inbody 720 uses proprietory equation for measurement of all body composition parameters. Present development reveals a possible regression equation for measurement of VFA. Correlation coefficient (R) for VFA measured from BIA device and commercial instrument Inbody 720 is obtained 98.3%. The BIA device developed is battery operated, handheld , low cost, safe, portable, rapid, easy to perform, and requires minimal operator training thus making it advantageous over other methods in addition to being an import substitute.

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