

Comparitive study of 2C molecular level, 3C water molecular level and 3C mineral molecular level of Indian subjects.

Ghazala Perveen Khan¹, Munna Khan², Shabana Mehfuz³

^{1,2,3}Department of Electrical Engineering, Jamia Millia Islamia University,
New Delhi, India.

Abstract: The aim of the present paper was to compare the 2C molecular level, 3C water molecular level and 3C mineral molecular level of Indian subjects. %BF were calculated using different equations. For 2C molecular level Siri 2C body equation developed in year 1956 was used. For 3C water molecular level Siri developed 3C equation in 1961 which was more accurate than the Siri 2C body composition equation. For 3C mineral molecular level Lohman in 1986 devised a 3C model that accounts for variability in the relative mineral content of the FFB. These equations were used to calculate BF% of Indian subjects. The results obtained were then validated with the Maltron-II Body composition analyser and it was found that the results were in close proximity with the results obtained from instrument. In addition to this statistical Analysis of the data is carried out with the help of statistical software R version (2.9.2) which is useful to study the correlation obtained from the the Instrument, and that obtained by scientists. Further different other parameters of statistics is formulated in tabular form.

Keywords: Bio Electrical Impedance Analysis, Body composition models, Body density (BD), Fat mass, Fat Free Mass (FFM), Total Body Water(TBW), Protein, Mineral.

- 1. Introduction:** Developing accurate body composition model and methods for evaluating and monitoring the health status of the country is the need of the hour. Different methods have been used till date and scientists have been working since decades to develop and design the appropriate method which could accurately calculate the body fat. Over the time researchers have tried to develop different compartment models of the body where they divide the human body into the different compartment models. At present there are more than 10 methods of calculating total body fat in vivo. It has to be taken into consideration that there are two types of methods for calculating the body fat of human body. The first type of method is called as reference method wherein what we do is that we measure some component of the body directly, from those measured component we calculate the body fat percentage. Examples of reference method include Under Water Weighing (UWW), Dual Energy X-Ray absorptiometry (DEXA) and 4 C models. The second type of method is called as prediction method. It is an indirect method of measuring something with the hopes, that we will get the same value of the body component as we have obtained through reference methods. Prediction method includes Skin fold method (SKF), Body Mass Index (BMI) and Bio Electrical Impedance method (BIA). Since 4 and 5 decades scientists and researchers have been working on a analysis of Human body composition. Body Composition Analysis is necessary to yield data about normal growth, maturity and longer life. By measuring body composition a person's health status can be more accurately assessed. Working on different body compartment models is one such concrete step in Human Body composition Analysis. For our study we have used Maltron-II Body composition Analyser to obtain different body components and compared the Body Fat %(BF%) obtain through instrument with different compartment models equations such as Siri classic 2C model equation for body composition developed in 1956, Siri 3C model equation developed in 1961 which was an improvement over Siri 2C model and Lohman 3C model developed in 1986. These scientist have already developed the equation for %BF. Our comparative work involves just putting the body component in the equations developed by scientists and see how close these values are with

the values that are obtained from instrument. Although, a similar work have already been before and in fact comparisons up to 6C model have been done, but our study in this case limit us for designing 4C and 6C model, because for that we need certain parameters of body component such as bone mineral, residual mass, Total Body Sodium (TBNa), Total Body Nitrogen (TBN), Total Body Chlorine (TBCl), which is not possible to measure through Maltron-II Bio Electrical Impedance Analyser (BIA). Due to this reason we have limited our study to the comparative study of 2C and 3C model and validated it the results obtained through Bio Electrical Impedance Analyser.

The figure below shows the different compartments in which we have divided the body. In 2C molecular level the human body is divided into Fat and Fat Free component. In 3C water molecular level the human body is divided into Fat, Water and Solids i.e. proteins and minerals. In 3C mineral molecular level that divided the human body into Fat, Mineral and water and protein combined. The detailed discussion about them is discussed later in Subjects and Methods.

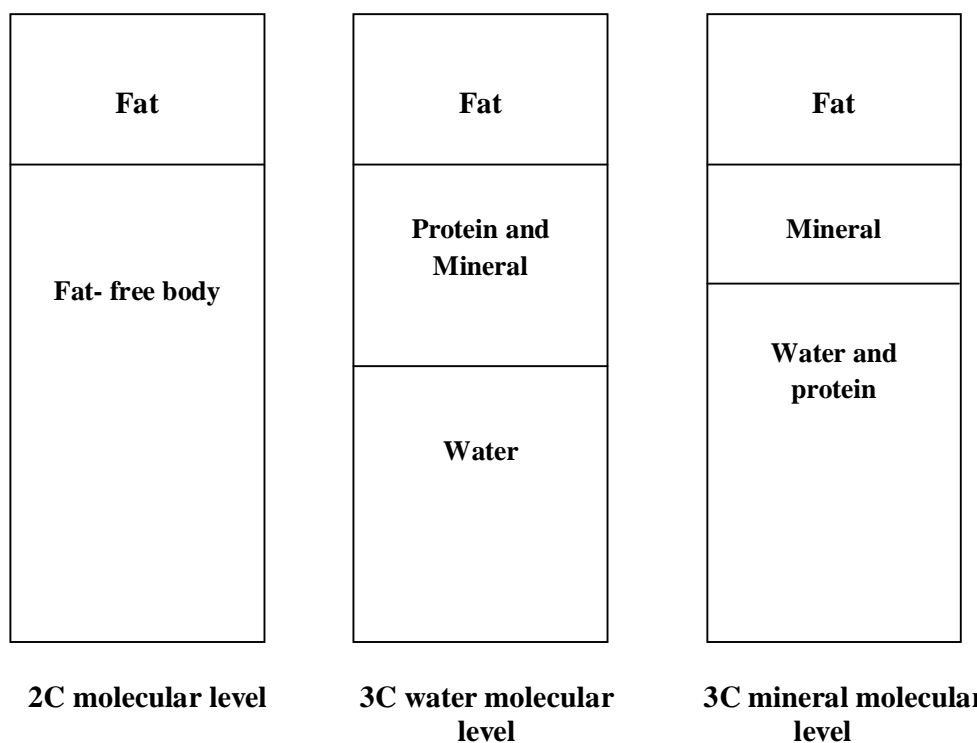


Fig 1: Different human body multicomponent models designed by Siri in year 1956 and 1961 and by Lohman in year 1986

2. Materials and methods:

2.1. Literature survey: A lot of scientists have been contributing in the past, for designing different body composition models. Their efforts have contributed a lot in the practice of medicine and understanding human physiology and metabolism in a better way. Earliest effort by scientists started on human foetus and infants in early 1900. However, direct chemical analysis of adult on whole body was more limited. The literature survey in this report is intended to present contribution made by different scientists in the field of body composition analysis while designing different body compartment models. It started with Behnke and colleagues more than some 5 decades ago where they divided the human body into Fat and Fat Free component. The earliest 2C model was pioneered by Behnke et.al in 1942 and established an inverse relationship between Db and adiposity. Later in 1953, Behnke and colleagues developed the concept of a reference body that consisted of FM and LBM and assumed that it was constant for all individuals. In 1956, Siri developed another 2-C model equation to convert Db to %BF. In 1961, Siri and in 1986 Lohman et.al modified the 2C model and developed the 3C model which divided the human body into fat, water and solids and obtain the equation for %BF of human body. With years attempts have been made by Selinger et.al (1977), Friedl et.al (1992), Heymsfield et.al (1996) and Baumgartner et.al (1991) to develop equation for % BF of human body using 4C model. A 6C model was developed by Wang et. al in yr. 1998 to obtain the % BF. This model divided the human body into nitrogen, calcium, potassium, sodium, and water and body chloride. This was the atomic level division of human body.

2.2 Subjects and Procedure:

Human Body Composition data of 10 Indian subjects (5males and 5 females) within the age group of 23 yrs to 50 yrs were studied through Maltron-II Body Composition Impedance Analyzer method. It should be noted that all the data that were taken were clinically normal and free from any disease, and were of normal built and sound health. All these data were taken at defence institute of Physiological and Applied Science where subjects were applied excitation current of $800\mu\text{A}$ at different frequencies of 5 KHz, 50 KHz, 100 KHz and 200 KHz at the source or drive distal electrodes on the hand and foot; and the voltage drop due to impedance was detected by sensor electrodes on the right wrist and right ankle. The flowchart showing the actual procedure carried out while studying the comparative study of body compartment models is shown in Figure 2; and the characteristic component of body parts of Indian subjects and their descriptive statistics is shown in Table 1 and Table 2. The flowchart given in figure below is self explanatory and need not need further explanation. However, for further explanation as discussed earlier, we obtained the data of subjects through instrument which included some vital information about the subject such as Age, Height, BMI, TBW, %Fat, %Fat Free Mass, Extra Cellular Water, Intra Cellular Water, Mineral, Protein, Body Density and many other such body composition parameters like Impedance, Capacitance, and Reactance at different frequencies. What we have done in our study is that we have simply tested Siri classic 2C model in 1956 and later his modified 3C model designed by him in 1961. In addition to testing Siri's 2C and 3C model we have also tested Lohman 3C body compartment model and compared the results with the one obtained from

instrument. The flowchart below shows the procedure carried out in comparing the different body compartment models.

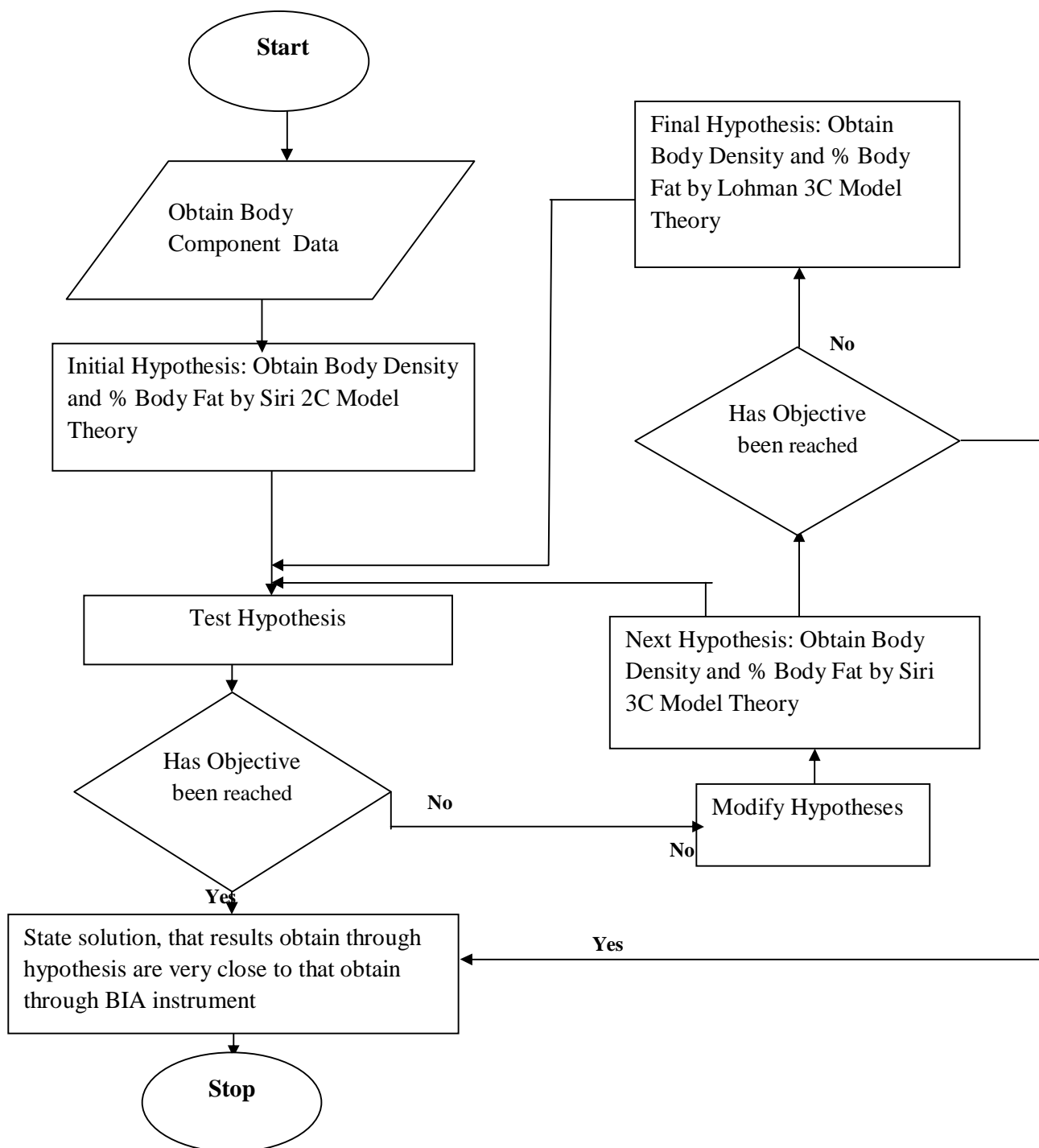


Fig 2: Flowchart showing the actual process while studying the comparative study of different body compartment models

Table 1: Characteristic component of the body parts of Indian subjects (n = 10)

| S.No. | Custom er ID | Sex | Age | Weight (Kg) | Db | %BF | %Mineral | %Protein | BCM(Kg) |
|-------|-----------------|-----|-----|----------------|--------|-------|----------|----------|---------|
| 1. | BB01 | F | 50 | 55 | 1.0238 | 33.51 | 5.095 | 12.5 | 19.38 |
| 2. | AAA8 | M | 31 | 65 | 1.0531 | 20.05 | 6.015 | 17.15 | 27.88 |
| 3. | AAA5 | M | 36 | 66 | 1.0421 | 25.05 | 5.378 | 15.303 | 26.95 |
| 4. | AAA2 | M | 29 | 57 | 1.0602 | 16.95 | 6.456 | 18.4 | 25.37 |
| 5. | AAA6 | M | 30 | 63 | 1.0519 | 20.63 | 7.216 | 20.55 | 26.45 |
| 6. | AAA1 | F | 34 | 56 | 1.0314 | 29.89 | 6.396 | 15.69 | 20.08 |
| 7. | AAA4 | F | 36 | 58 | 1.02 | 35.31 | 4.8 | 11.8 | 20 |
| 8. | AAA3 | M | 29 | 66 | 1.0456 | 23.45 | 6.3 | 18 | 26.81 |
| 9. | AAA7 | F | 23 | 48 | 1.0549 | 19.31 | 8.021 | 19.66 | 19.05 |
| 10. | AAA0 | F | 27 | 44 | 1.0594 | 17.25 | 7.9 | 19.46 | 18.14 |

Db is the density of body and BCM is Body Cellular Mass. Value of Sex for female=0 and for male=1.

Table 2: Descriptive statistics of Indian subjects (n = 10)

| Variables | Mean ± S.D. |
|-------------------------------|------------------------|
| TBW | 30.549 ± 4.567 |
| FFM | 43.779 ± 4.528 |
| Weight | 57.601 ± 7.375 |
| %Mineral | 0.063568 ± 0.010485078 |
| %Protein | 0.168513 ± 0.028348 |
| Age | 32.5 ± 6.974955 |
| Body Density | 1.04424±0.013826972 |
| % Body Fat (%BF) | 24.114 ± 6.312 |
| % Fat Free Mass (%FFM) | 75.86 ± 6.409 |

TBW is the Total Body Water and FFM is Fat Free Mass content of the body.

2.3.1 Siri Two Compartment molecular level models: It is to be noted that since earliest times scientists and researchers have been working sometimes on the chemical analysis of specific organs of Human body and sometimes on whole body. Increased risk of cardiovascular disease obesity and many other such diseases associated with fat was the initial cause or reasons which lead the scientists to develop 2 compartment models. However, direct measurements of body mass have never been easy and remain a significant and tedious task. The most important contribution in the development of 2 compartment models had been by Siri in the year 1956 where he divided the human body into fat and fat free component.

Derivation of Siri 2 Compartment Molecular level model body Composition Analysis: The classic 2 Compartment model partitions the body into 2 parts; Fat and Fat Free Component. The assumed densities of Fat and Fat Free Mass component of the body are assumed to be .9007 Kg/L and 1.1 Kg/L. Now, as a random example we have taken the Bio Electrical Impedance Analysis body composition data of customer ID AAA2 and from that we have shown how Siri derived his 2C body composition model. If the body is partitioned into Fat and Fat Free component, then formula for Body Density is given as below:

$$\frac{1}{D_b} = \frac{FM}{FM D_b} + \frac{FFM}{FFM D_b}$$

Where D_b is the density of body, $F M D_b$ is the Fat mass density of the body, $F F M D_b$ is the Fat Free Mass Density of the body. Now for Customer ID AAA2; $F M=0.1695$, $F F M=0.8305$, putting this in above equation, we get body density of customer ID AAA2 as 1.060236, which is very close to the body density of customer ID AAA2 which we have obtained through BIA instrument i.e. 1.0602. Siri also gave 2 Compartment model formulas for % Body Fat calculation as given below:

$$\%BF = \frac{497.1}{D_b} - 451.9$$

For customer ID AAA2 $D_b = 1.0602$; putting this value in the above equation we get % BF of customer ID AAA2 as 16.97% and the one obtained from BIA instrument is 16.95%. So, both these values are pretty close to each other. However, Siri modified his 2 compartment model and Lohman developed 3 Compartment models which are discussed below.

2.3.2 Siri Three Compartment water molecular level models: Generally two compartment models provide the reasonable estimates of % body fat. While designing 2 Compartment model by Brozek et.al; it was assumed that that FFM density was constant across all the subjects. Siri in 1956 derived earlier accounted for variation in subject hydration level. However, age, gender, ethnicity, level of body fatness and physical activity level still effected the relative proportion of water, mineral and protein. In an order to overcome the shortcomings that remained in Siri classic two compartment model. Siri updated his model in year 1961 and divided the body into three components Fats, Water and Solids i.e. (proteins and minerals).

Derivation of Siri 3 Compartment level model water molecular level body Composition Analysis: The assumed densities of Fat, Total Body water and (Mineral + Protein fraction) component of the body are assumed to be 0.9007 Kg/L, 0.9937 Kg/L and constant density for (Mineral + Protein Fraction) i.e. 1.565 kg/L. . Now, as a random example we have again taken the Bio Electrical Impedance Analysis body composition data of customer ID AAA2 and from that we have shown how Siri derived his 3C body composition model. If the body is partitioned into Fat, Water and Solids (Minerals + Protein), then formula for Body Density is given as below:

$$\frac{1}{D_b} = \frac{F M}{F M D_b} + \frac{T B W}{T B W D_b} + \frac{\text{Minerals + Proteins}}{(\text{Minerals + Proteins fraction}) D_b}$$

Where $T B W D_b$ is the Total Body Water density and constant density is assumed for minerals and proteins fractions as discussed earlier. Now for Customer ID AAA2 $F M = 0.1695$ $T B W = 0.5817$ and $\text{Minerals} = 0.06456$, $\text{Proteins} = 0.184$. Putting all these values in the above equation, we get D_b of Customer ID AAA2 as 1.0725 and the one obtained from BIA instrument is 1.0602 which is very close to the value obtained from Instrument. Siri also gave 3 Compartment model formulas for % Body Fat calculation as given below:

$$\%BF = \left(\frac{2.118}{Db} - 0.78 \times \frac{TBW}{BW} - 1.354 \right) \times 100$$

Where BW is the body weight. For Customer ID AAA2 BW = 57 Kg. Putting this value and all other values in the above equation, we get BF% as 18.99% which is very close to value obtained from BIA instrument i.e. 16.95%

2.3.3 Lohman Three Compartment mineral molecular level models: As research proceeded further, it was found that the results obtained from Siri water molecular level were not very much accurate. Lohman in 1986 devised a 3C model that accounted for variability in the relative mineral content of FFB and divided the body into fat, mineral, and protein + water fractions.

Derivation of Lohman 3 Compartment level model molecular level body Composition Analysis: The assumed densities of Fat, Mineral and (Water + Protein fraction) component of the body are assumed to be 0.9007 Kg/L, 3.038 Kg/L and constant density for (Water + Protein Fraction) i.e. 1.0486 Kg/L. . Now, as a random example we have again taken the Bio Electrical Impedance Analysis body composition data of customer ID AAA2 and from that we have shown how Lohman derived his 3C body composition model. If the body is partitioned into Fat, Mineral and (Water + Protein) fraction, then formula for Body Density is given as below:

$$\frac{1}{Db} = \frac{FM}{FM Db} + \frac{Mineral}{Mineral Db} + \frac{Water + Proteins}{(Water + Proteins fraction) Db}$$

Where Mineral Db is the density of Minerals in body, Water and proteins fractions have constant density of 1.0486 Kg/L as discussed earlier. Now for Customer ID AAA2 FM = 0.1695 Minerals = 0.06456 and Total Body Water = 0.5817, Proteins = 0.184. Putting all these values in the above equation, we get Db of Customer ID AAA2 as 1.06424 and the one obtained from BIA instrument is 1.0602 which is very close to the value obtained from Instrument. Lohman also modified Siri 3 Compartment model formulas for % Body Fat calculation as given below:

$$\%BF = \left(\frac{6.386}{Db} + 3.961 \times \frac{Mineral}{BW} - 6.09 \right) \times 100$$

Where, BW is the body weight. For Customer ID AAA2; BW = 57 Kg, Mineral = 0.06456 Kg Putting this value and all other values in the above equation, we get BF% as 18.911% which is very close to value obtained from BIA instrument i.e. 16.95% .

Table 3: Data of Human body of Indian subjects

| S.No. | Custo mer ID | FFM | Weigh t (Kg) | Db | %BF | Mineral | Protein | BCM(K g) | TBW |
|-------|--------------------|-------|-----------------|--------|-------|---------|---------|-------------|-------|
| 1. | BB01 | 36.57 | 55 | 1.0238 | 33.51 | 0.05095 | 0.125 | 19.38 | 26.95 |
| 2. | AAA8 | 51.97 | 65 | 1.0531 | 20.05 | 0.06015 | 0.1715 | 27.88 | 36.9 |
| 3. | AAA5 | 49.47 | 66 | 1.0421 | 25.05 | 0.05378 | 0.15303 | 26.95 | 35.81 |
| 4. | AAA2 | 47.34 | 57 | 1.0602 | 16.95 | 0.06456 | 0.184 | 25.37 | 33.16 |
| 5. | AAA6 | 50 | 63 | 1.0519 | 20.63 | 0.07216 | 0.2055 | 26.45 | 33.33 |
| 6. | AAA1 | 39.26 | 56 | 1.0314 | 29.89 | 0.06396 | 0.1569 | 20.08 | 26.99 |
| 7. | AAA4 | 37.52 | 58 | 1.02 | 35.31 | 0.048 | 0.118 | 20 | 27.92 |
| 8. | AAA3 | 50.52 | 66 | 1.0456 | 23.45 | 0.063 | 0.18 | 26.81 | 34.46 |
| 9. | AAA7 | 38.73 | 48 | 1.0549 | 19.31 | 0.08021 | 0.1966 | 19.05 | 25.43 |
| 10. | AAA0 | 36.41 | 44 | 1.0594 | 17.25 | 0.079 | 0.1946 | 18.14 | 24.54 |

3. Statistical Analysis: The correlation between variables of results obtained i.e. BIA measured Db i.e. Body density of subjects, BIA measured % BF i.e. % Body Fat of the subjects, Siri 2 compartmental obtained Db, Siri 2 compartmental %BF, Siri 3 compartmental Db, Siri 3 compartmental %BF, Lohman's 3 compartmental Db and Lohman's 3 compartmental %BF is quite high, as can be shown in the Scatter Matrix Plot below. Some correlation are positive whereas some are negative. In case of positive correlation there will be uptrend whereas in case of negative correlation there will downtrend. For example correlation between BIADb (BIA measured Db) and BIABF (BIA measured % BF) is negative whereas correlation between BIADb and S2CDb (Siri 2 compartmental obtained Db) is positive. As compared to S3CDb (Siri 3 compartmental Db); S2CBF(Siri 2 compartmental %BF) is more strongly linearly related as it is evident from the graph below. The correlation between S3CDb (Siri 3 compartmental Db) and L3CDb (Lohman's 3 compartmental Db) is also quiet high. However, L3CDb (Lohman's 3 compartmental Db) and L3CBF (Lohman's 3 compartmental %BF) are not so linear. Similarly other trends can be interpreted.

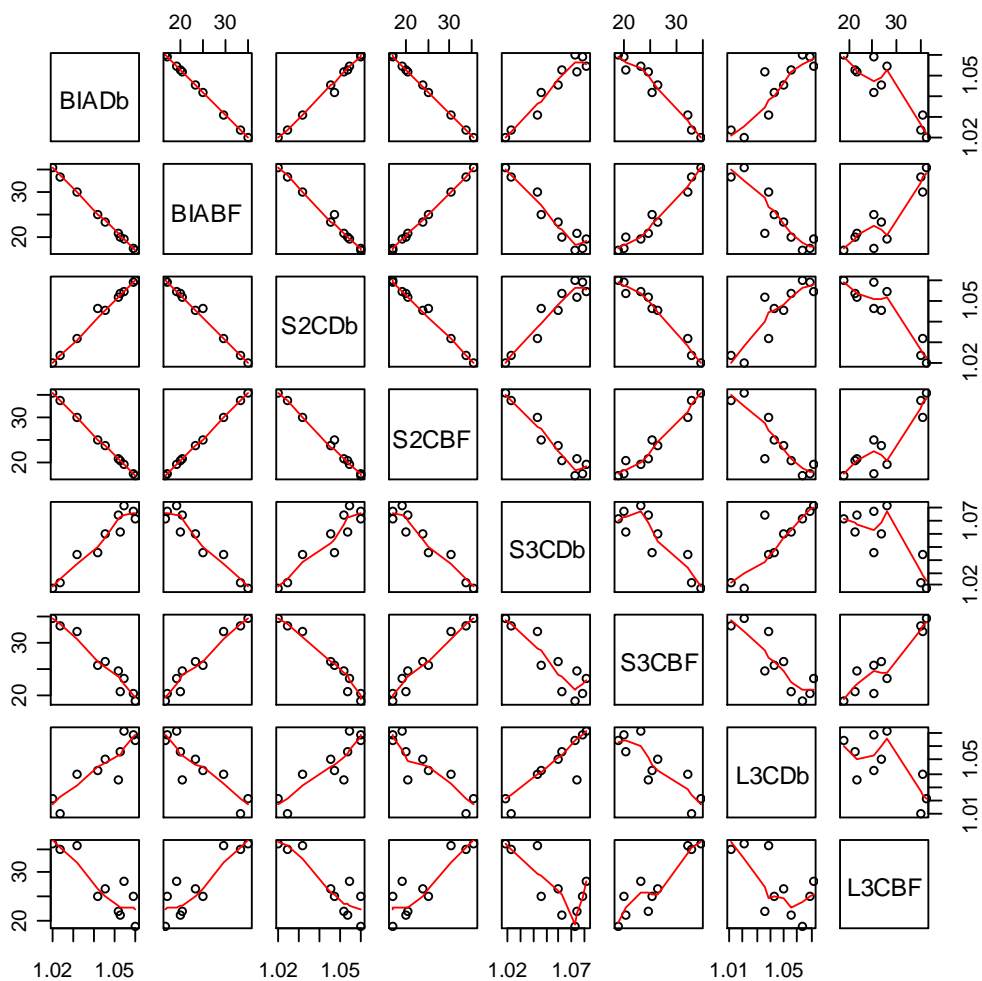


Fig 2: Scatter matrix Plot showing the actual process while studying the comparative study of different body compartment models and experimental data obtained from Maltron-II BIA Analyser of the subjects.

Table4: Descriptive Statistics of subjects (N=10) measured through BIA, Siri 2C method, Siri 3C model and Lohman 3C model

| S.No. | Method used | Standard Error | Residual R ² | Multiple R ² | Adjusted R ² | F statistics | P value |
|-------|---|--------------------------------|-------------------------|-------------------------|-------------------------|---------------------|-----------|
| 1. | Experimental method using BIA Maltron-II Analyser | Intercept =1.846, BIADb= 1.767 | 0.07728 on 8 df | 0.9999 | 0.9999 | 6.672e+04 | < 2.2e-16 |
| 2. | Siri 2 compartmental method | Intercept =15.89, S2CDB= 15.21 | 0.6627 on 8 df | 0.9913 | 0.9902 | 910.6 on 1 and 8 DF | 1.578e-09 |
| 3. | Siri 3 compartmental method | Intercept =15.89, S3CDB= 15.21 | 2.587 on 8 df | 0.7628 | 0.7331 | 25.73 on 1 and 8 DF | 0.0009626 |
| 4. | Lohman's 3 compartmental method | Intercept =15.89, L3CDB= 84.75 | 2.587 on 8 df | 0.4083 | 0.3343 | 5.519 on 1 and 8 DF | 0.04673 |

Table 5: Siri 2 Compartmental model of human body composition for calculating body density of Indian subjects

| FM | FFM | 1/Db | Db |
|--------|---------|-------------|----------|
| 0.3351 | 0.6649 | 0.976498511 | 1.024067 |
| 0.2005 | 0.7995 | 0.949422823 | 1.053271 |
| 0.2505 | 0.7495 | 0.959480656 | 1.04223 |
| 0.1695 | 0.8305 | 0.8305 | 0.8305 |
| 0.2063 | 0.7936 | 0.950498622 | 1.052079 |
| 0.2989 | 0.70107 | 0.969189367 | 1.03179 |
| 0.3531 | 0.6469 | 0.980119331 | 1.020284 |
| 0.2345 | 0.7654 | 0.956171241 | 1.045838 |
| 0.1931 | 0.8069 | 0.947934263 | 1.054925 |
| 0.1725 | 0.8275 | 0.943790436 | 1.059557 |

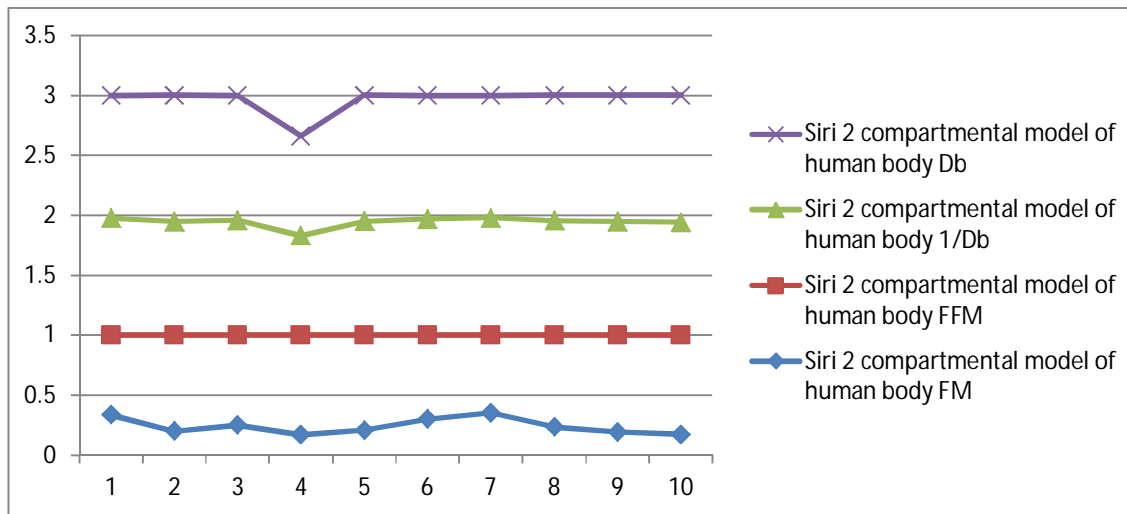


Fig 3: Siri 2 compartmental model of human body and various parameters used in Siri 2 C equation for calculating Db and % BF.

Table 6: Siri 2 Compartmental model to calculate %BF

| Db | BW | Mineral | %BF |
|----------|----|---------|----------|
| 1.024067 | 55 | 0.05095 | 33.51741 |
| 1.053271 | 65 | 0.06015 | 20.05809 |
| 1.04223 | 66 | 0.05378 | 25.05783 |
| 1.060235 | 57 | 0.06456 | 16.95824 |
| 1.052079 | 63 | 0.07216 | 20.59287 |
| 1.03179 | 56 | 0.06396 | 29.88403 |
| 1.020284 | 58 | 0.048 | 35.31732 |
| 1.045838 | 66 | 0.063 | 23.41272 |
| 1.054925 | 48 | 0.08021 | 19.31812 |
| 1.059557 | 44 | 0.079 | 17.25823 |

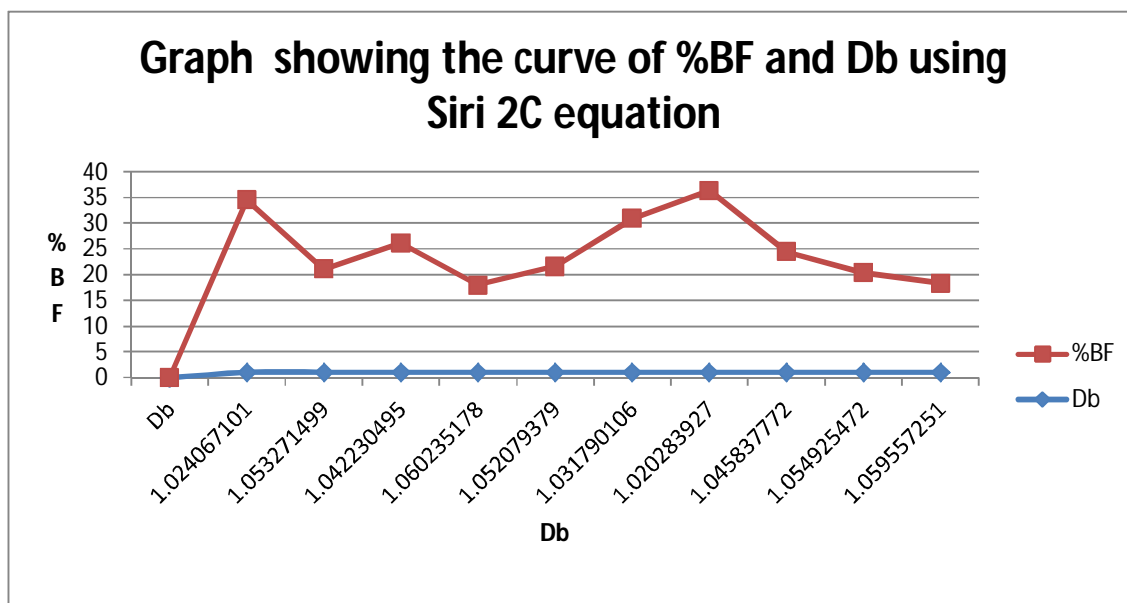


Fig 4: Siri 2 compartmental model of human body showing the curve pattern between % BF and Db where % BF is the Body Fat percentage of subjects(N=10) and Db is the Body density.

Table 7: Siri 3 Compartmental model for calculating body density of Indian subjects.

| FM | BW | TBW | TBW/BW | Mineral | Protein | Mineral+Protein | 1/Db | Db |
|--------|----|-------|----------|---------|---------|-----------------|----------|----------|
| 0.3351 | 55 | 26.95 | 0.49 | 0.05095 | 0.125 | 0.17595 | 0.977579 | 1.022936 |
| 0.2005 | 65 | 36.9 | 0.567692 | 0.06015 | 0.1715 | 0.23165 | 0.941915 | 1.061667 |
| 0.2505 | 66 | 35.81 | 0.542576 | 0.05378 | 0.15303 | 0.20681 | 0.95628 | 1.045719 |
| 0.1695 | 57 | 33.16 | 0.581754 | 0.06456 | 0.184 | 0.24856 | 0.932454 | 1.072439 |
| 0.2063 | 63 | 33.33 | 0.529048 | 0.07216 | 0.2055 | 0.27766 | 0.938864 | 1.065117 |
| 0.2989 | 56 | 26.99 | 0.481964 | 0.06396 | 0.1569 | 0.22086 | 0.957998 | 1.043844 |
| 0.3531 | 58 | 27.92 | 0.481379 | 0.048 | 0.118 | 0.166 | 0.98253 | 1.017781 |
| 0.2345 | 66 | 34.46 | 0.522121 | 0.063 | 0.18 | 0.243 | 0.941056 | 1.062636 |
| 0.1931 | 48 | 25.43 | 0.529792 | 0.08021 | 0.1966 | 0.27681 | 0.924415 | 1.081766 |
| 0.1725 | 44 | 24.54 | 0.557727 | 0.079 | 0.1946 | 0.2736 | 0.927605 | 1.078045 |

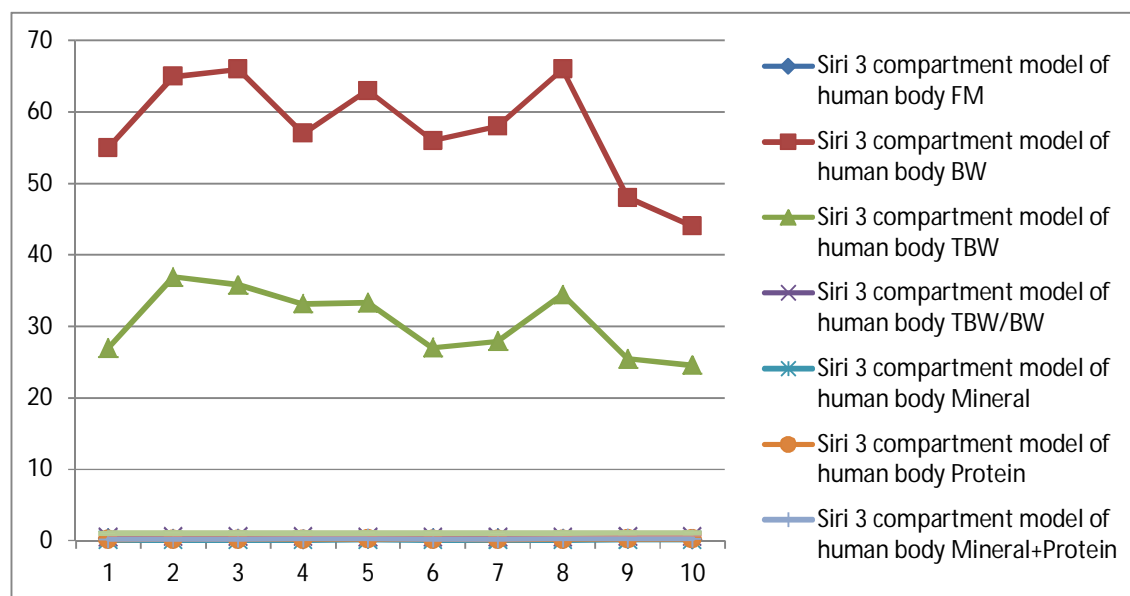


Fig 4: Siri 3 compartmental model of human body and various parameters used in Siri 3 C equation for calculating Db and % BF.

Table 8: Siri 3 compartmental body composition model for calculating the %BF

| Db | BW | TBW | %BF |
|----------|----|-------|----------|
| 1.022936 | 55 | 26.95 | 33.43108 |
| 1.061667 | 65 | 36.9 | 19.81758 |
| 1.045719 | 66 | 35.81 | 24.81916 |
| 1.072439 | 57 | 33.16 | 16.71691 |
| 1.065117 | 63 | 33.33 | 22.18568 |
| 1.043844 | 56 | 26.99 | 29.91067 |
| 1.017781 | 58 | 27.92 | 35.15219 |
| 1.062636 | 66 | 34.46 | 23.19021 |
| 1.081766 | 48 | 25.43 | 19.06721 |
| 1.078045 | 44 | 24.54 | 17.56403 |

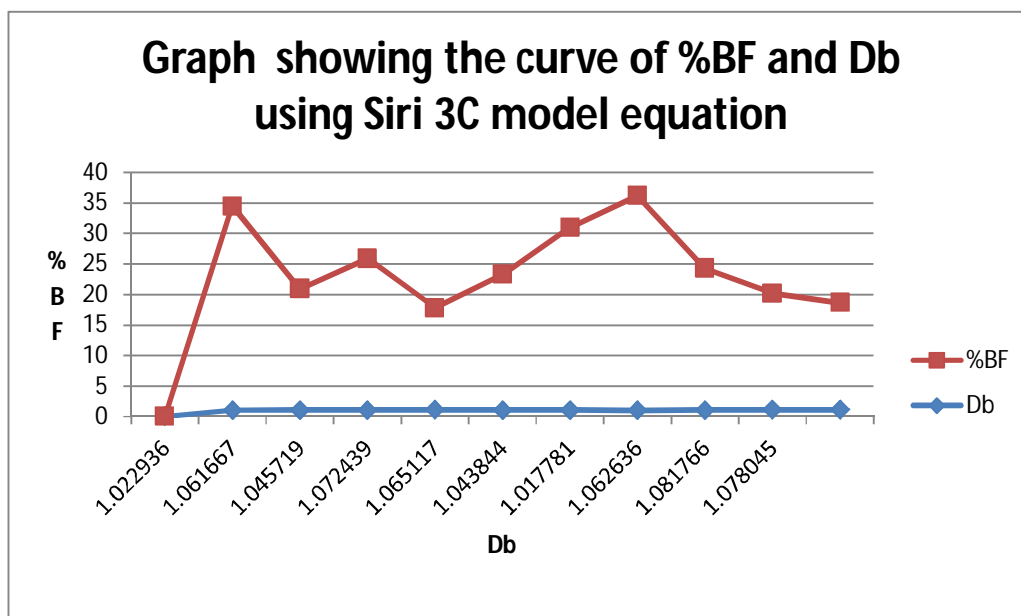


Fig 5: Siri 3 compartmental model of human body showing the curve pattern between % BF and Db where % BF is the Body Fat percentage of subjects(N=10) and Db is the Body density

Table 9: Lohman 3 Compartmental model for calculating body density of Indian subjects.

| FM | Mineral | BW | TBW | TBW/BW | Protein | (TBW/BW)+Protein | 1/Db | Db |
|--------|---------|----|-------|----------|---------|------------------|----------|----------|
| 0.3351 | 0.05095 | 55 | 26.95 | 0.49 | 0.125 | 0.615 | 0.975311 | 1.025314 |
| 0.2005 | 0.06015 | 65 | 36.9 | 0.567692 | 0.1715 | 0.739192308 | 0.947336 | 1.055591 |
| 0.2505 | 0.05378 | 66 | 35.81 | 0.542576 | 0.15303 | 0.695605758 | 0.959186 | 1.042551 |
| 0.1695 | 0.06456 | 57 | 33.16 | 0.581754 | 0.184 | 0.765754386 | 0.939701 | 1.064168 |
| 0.2063 | 0.07216 | 63 | 33.33 | 0.529048 | 0.2055 | 0.734547619 | 0.9533 | 1.048988 |
| 0.2989 | 0.06396 | 56 | 26.99 | 0.481964 | 0.1569 | 0.638864286 | 0.962161 | 1.039327 |
| 0.3531 | 0.048 | 58 | 27.92 | 0.481379 | 0.118 | 0.59937931 | 0.979428 | 1.021004 |
| 0.2345 | 0.063 | 66 | 34.46 | 0.522121 | 0.18 | 0.702121212 | 0.95067 | 1.05189 |
| 0.1931 | 0.08021 | 48 | 25.43 | 0.529792 | 0.1966 | 0.726391667 | 0.933516 | 1.071219 |
| 0.1725 | 0.079 | 44 | 24.54 | 0.557727 | 0.1946 | 0.752327273 | 0.93498 | 1.069541 |

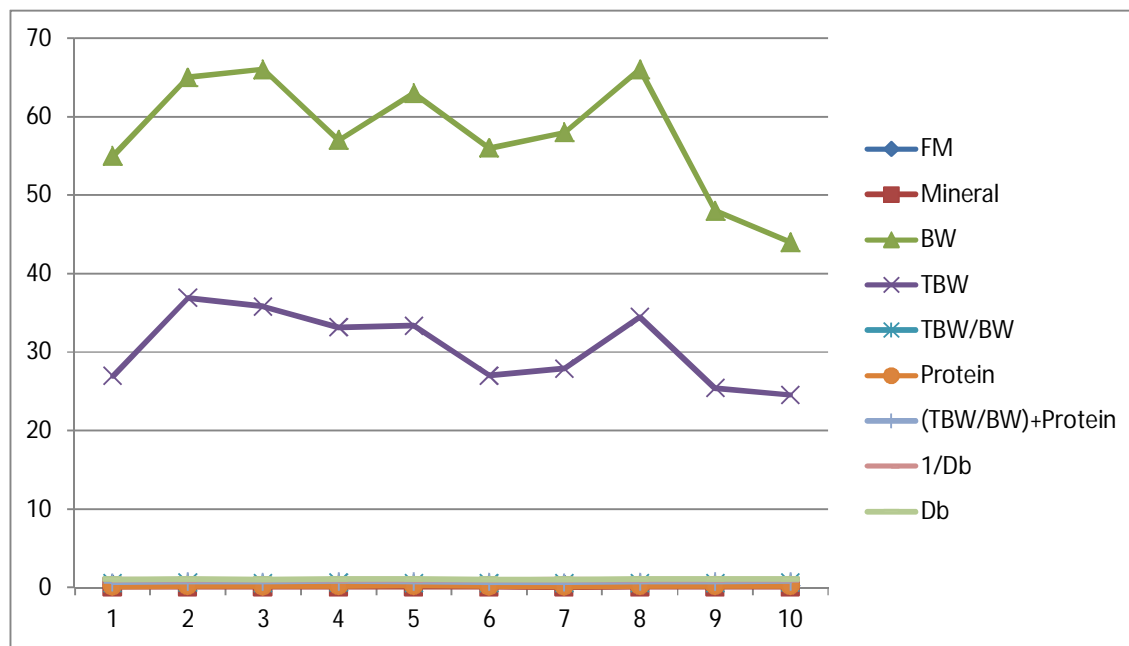


Fig 6: Lohman 3 compartmental model of human body and various parameters used in Lohman 3 C equation for calculating Db and % BF.

Table 10: Lohman 3 compartmental body composition model for calculating the %BF

| Db | Mineral | BW | %BF |
|----------|---------|----|----------|
| 1.025314 | 0.05095 | 55 | 34.01489 |
| 1.055591 | 0.06015 | 65 | 19.79457 |
| 1.042551 | 0.05378 | 66 | 24.83824 |
| 1.064168 | 0.06456 | 57 | 16.66543 |
| 1.048988 | 0.07216 | 63 | 28.3598 |
| 1.039327 | 0.06396 | 56 | 30.77063 |
| 1.021004 | 0.048 | 58 | 35.47558 |
| 1.05189 | 0.063 | 66 | 23.052 |
| 1.071219 | 0.08021 | 48 | 18.91445 |
| 1.069541 | 0.079 | 44 | 19.37046 |

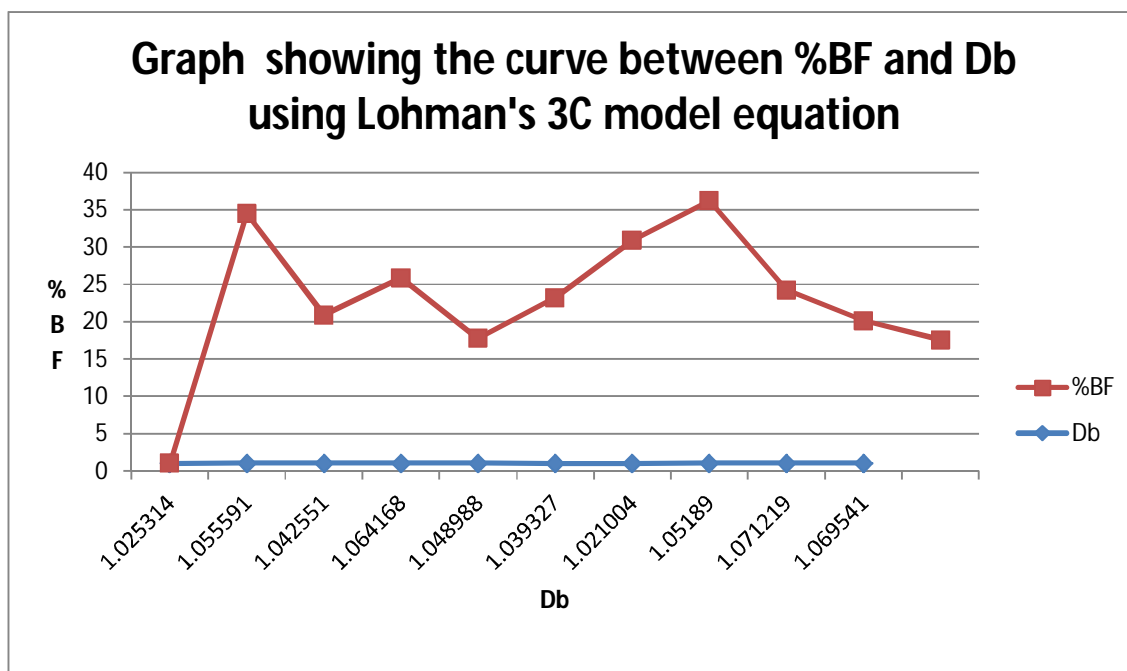


Fig 7: Lohman 3 compartmental model of human body showing the curve pattern between % BF and Db where % BF is the Body Fat percentage of subjects(N=10) and Db is the Body density

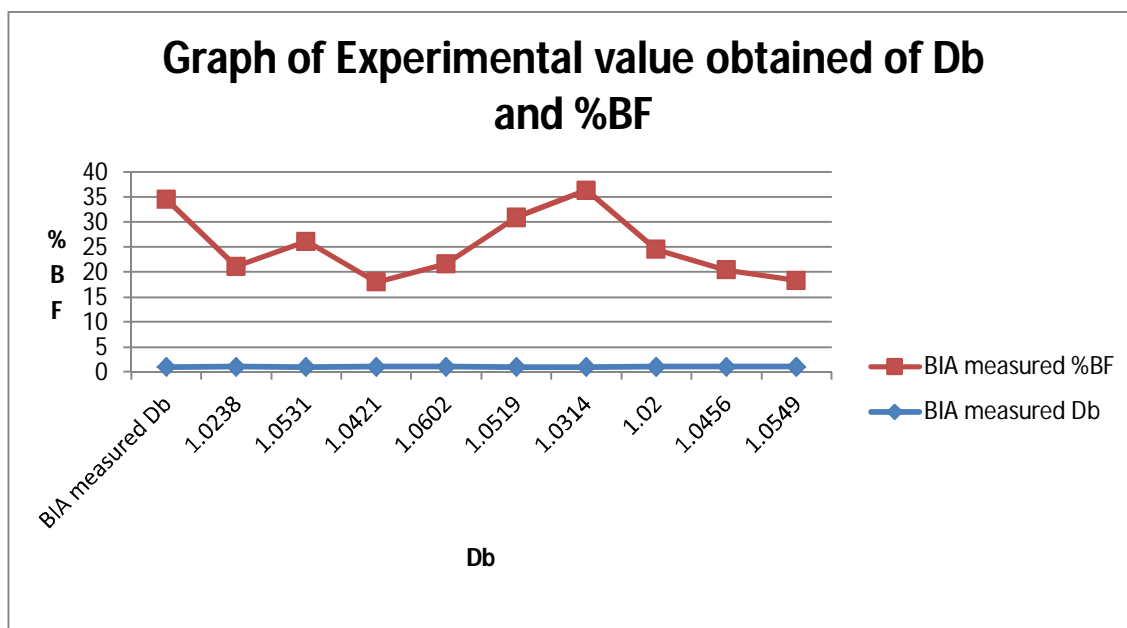


Fig 8: Curve pattern between % BF and Db where % BF is the Body Fat percentage of subjects(N=10) and Db is the Body density measured through Experimental process of human body through Maltron-II BIA Analyser.

Table11: The comparative study showing the measured and obtained Body Density % body Fat of the subject through different compartment models like Siri 2C Model, Siri 3C Model and Lohman’s 3C models.different body compartment models.

| S.No. | BIA measured Db | BIA measured %BF | Db obtained by Siri 2C model | %BF obtained by Siri 2C model | Db obtained by Siri 3C model | %BF obtained by Siri 3C model | Db obtained by Lohman 3C model | %BF obtained by Lohman 3C model |
|-------|-----------------|------------------|------------------------------|-------------------------------|------------------------------|-------------------------------|--------------------------------|---------------------------------|
| 1. | 1.0238 | 33.51 | 1.024 | 33.64 | 1.02288 | 32.9 | 1.011 | 34.9 |
| 2. | 1.0531 | 20.05 | 1.0537 | 20.1349 | 1.06178 | 20.68 | 1.05578 | 21.2 |
| 3. | 1.0421 | 25.05 | 1.046811 | 25.117 | 1.0458 | 25.525 | 1.0426 | 25.103 |
| 4. | 1.0602 | 16.95 | 1.060236 | 16.97 | 1.0725 | 18.99 | 1.06424 | 18.911 |
| 5. | 1.0519 | 20.63 | 1.0519 | 20.67 | 1.0746 | 24.68 | 1.0358 | 21.8 |
| 6. | 1.0314 | 29.89 | 1.0317 | 30.066 | 1.04397 | 32.018 | 1.03942 | 35.49 |
| 7. | 1.02 | 35.31 | 1.02028 | 35.45 | 1.01798 | 34.46 | 1.02124 | 36.086 |
| 8. | 1.0456 | 23.45 | 1.04574 | 23.72 | 1.06 | 26.46 | 1.05 | 26.69 |
| 9. | 1.0549 | 19.31 | 1.05492 | 19.329 | 1.08188 | 23.24 | 1.07132 | 28.13 |
| 10. | 1.0594 | 17.25 | 1.059558 | 17.32 | 1.078 | 20.274 | 1.069 | 25.08 |

3. Results and Discussion

The study was able to develop and predict Body density and %Body Fat for Indian subjects. From the results it was seen that Siri 2C results, Siri 3C and Lohman Body Compartment results i.e obtained body density and% Body Fat were very close to the one obtained from BIA instrument. Results clearly show differences in results while calculating body density and % Body Fat through different compartment models. The results obtained by Siri 3C model and Lohman 3C model overestimates the results obtained as that from the instrument. This is in contrary to literature survey which clearly says, that results from 3C model are more accurate then 2C model. The above inaccuracy in the results may be due to the fact that Siri 3C water molecular body compartmental equation adjusts body density for relative amount of water in the body whereas Lohman mineral molecular body compartmental equation adjusts body density for total amount of Total body mineral in the body. Water accounts for 74- 79% of FFM whereas mineral 4-7% of FFM. Lohman equation assumed or overestimated FFM density then found in boys, that resulted in overestimation of %BF. Further, M/FFM ratio differs with age and gender that is also one of the reason for high overestimation of %BF.

4. Conclusion:

The study was able to develop and predict Body density and %Body Fat for Indian subjects. A similar study was done on Caucasian subjects by Withers et. al where 48 subjects volunteered for the study. Our study is a bit different as we have used Bio Electrical Impedance Analyser for experimental data. In our case 10 subjects volunteered for the study and we have compared Siri 2C model, Siri 3C model and Lohman 3C model. Our Lohman's model is not so strongly linearly related, this may be due to the fact discussed above in results i.e. Lohman formulated the following equation to calculate Human body density

$$\frac{1}{Db} = \frac{FM}{FM Db} + \frac{Mineral}{Mineral Db} + \frac{Water + Proteins}{(Water + Proteins fraction) Db}$$

and Siri formulated the following equation to calculate Human Body Density in its 3C model.

$$\frac{1}{Db} = \frac{FM}{FM Db} + \frac{TBW}{TBW Db} + \frac{Minerals + Proteins}{(Minerals + Proteins fraction) Db}$$

Now water accounts for 74- 79% of FFM whereas mineral 4-7% of FFM. . Lohman equation assumed or overestimated FFM density then found in boys, that resulted in overestimation of %BF. Further, M/FFM ratio differs with age and gender that is also one of the reason for high overestimation of %BF. Furthermore, the subjects who participated in study were very less. But still results of body density obtained through Maltron-II BIA Analyser and that obtained through Siri 2C, Siri 3C and Lohman's 3C model are very close to each other.

REFERENCES

- [1] Behnke, A.R., Feen, B.G., and Welham, W.C. The specific gravity of healthy men. Body weight and volume as an index of obesity. *Journal of American Medical Association*, 1942. 118:495-498.
- [2] Behnke AR. Anthropometric evaluation of body composition throughout life. *Annual New York Academy of Sciences* 1963, 110: 450–464.
- [3] Behnke, A.R., Osserman, E.F., and Welham, W.C. Lean body Mass. *Archives of Internal Medicine*, 1953.91:585-601
- [4] Brozek, J. and Keys, A. Evaluation of leanness-fatness in man: Norms and interrelationships. *British Journal of Nutrition*, 1951.5:194-206
- [5] Heymsfield SB and Wang ZM, Baumgartner RN, Ross R. Advances in models and methods. *Annual Review on Nutrition*, 1997, 17:527-58
- [6] Heyward V.H., Kravitz Len. Getting a grip on body composition.
- [7] Heyward VH, Wagner DR. *Applied Body Composition*, 2nd Edition. Champaign, IL: Human Kinetics, 2004
- [8] Kenneth J E, Manjiyang Y, Roman J S, Alessandro U, William W W and William C H. Body-composition assessment in infancy: air-displacement plethysmography compared with a reference 4-compartment model. *American Journal of Clinical Nutrition*, Vol. 85, No. 1, 90-95, January 2007.
- [9] Laura EC, Dale AS, Abigail CW, Randall C, Rachel NC, Andrea CB. Bioelectrical Impedance vs. Four-compartment Model to Assess Body Fat Change in Overweight Adults. *Journal of Obesity*. 85–92; doi:10.1038/oby.2007.510
- [10] Lohman TG: Applicability of body composition techniques and constants for children and youths. In *Exercise and Sport Sciences Reviews*, ed. KB Pandolf, (1986) pp 325–357. New York: Macmillan.
- [11] Moom JR, Holly HR, Tobkin SE, Teramoto M, Karabulut M, Roberts MD, Ryan ED, Kin SJ, Dalbo VJ, Walter AA, Smith AT, Cramer JT and Stout JR. Percent Body estimation in college women using field and laboratory methods. *Journal of International Society of sports Nutrition* 4:16 doi:10.1186/1550.2783-4-16
- [12] Roemmich J N, Clark P A, Weltman A, Rogol AD. Alterations in growth and body composition during puberty. I. Comparing multicompartment body composition models. *Journal of Applied Physiology* 83:927-935, 1997.
- [13] Shah AH and Bilal R; Body composition, its Significance and model for assessment: *Pakistan Journal of Nutrition* 2009.

[14] Silva M A, Shen W, Wang Z, Aloia J F, Nelson M E, Heymsfield S B, Sardinha L B, Heshka S. Three compartmental model: critical evaluation based on neutron activation analysis. *American Journal of Physiology of endocrinology and metabolism*. 287:E962-E969, 2004.

[15] Siri WE. The gross composition of the body. *Adv Biol Med Phys* 4:239–280, 1956.

[16] Siri WE. Body composition from fluid spaces and density: analysis of method. In: *Techniques for Measuring Body Composition*, edited by Brozek J and Henschel A. Washington, DC: National Academy of Sciences, National Research Council, 1961, p. 223–244.

[17] Withers R.T., Laforgia J., Pillans R.K., Shipp N.J., Chatterton B.E., Schultz C.G., and Leaney F. Comparisons of two-, three-, and four-compartment models of body composition analysis in men and women. *Journal of Applied Physiology* 85:238-245, 1998.

[18] Wang Z M, Deurenberg P, Guo SS, Pietrobelli A, Wang J, Pierson Jr. R N and Heymsfield SB. Six-compartment body composition model: Inter-method comparisons of total body fat measurement. *International Journal of Obesity* 14.

[19]

<http://www.drkrider.com/FORMULA%20FOR%20LIFE/measurement&diaries/bodycompartments.htm>