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Multicompartmental Models to Assess the Body Composition of Indian Subjects and Validation of Result by Developing Prediction Equation

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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 prediction equations developed from the clinical data of 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 (2.12.1) 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. 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 by developing Prediction Equation of 2C model and different 3C models.

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.

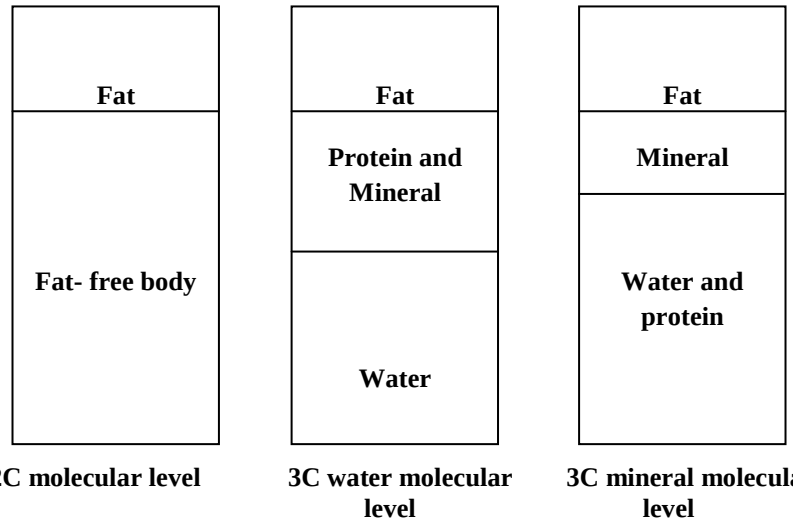


Fig1. *Different human body multicomponent models designed by Siri in year 1956 and 1961 and by Lohman in year 1986*

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 collegues 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 70 Indian subjects (35males and 35 females) within the age group of 17 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 800µA 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. 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'c 2C and 3C model we have also tested Lohman 3C body compartment model and compared the results with the results obtained from 2C and 3C prediction equation. The flowchart below shows the procedure carried out in comparing the different body compartment models.

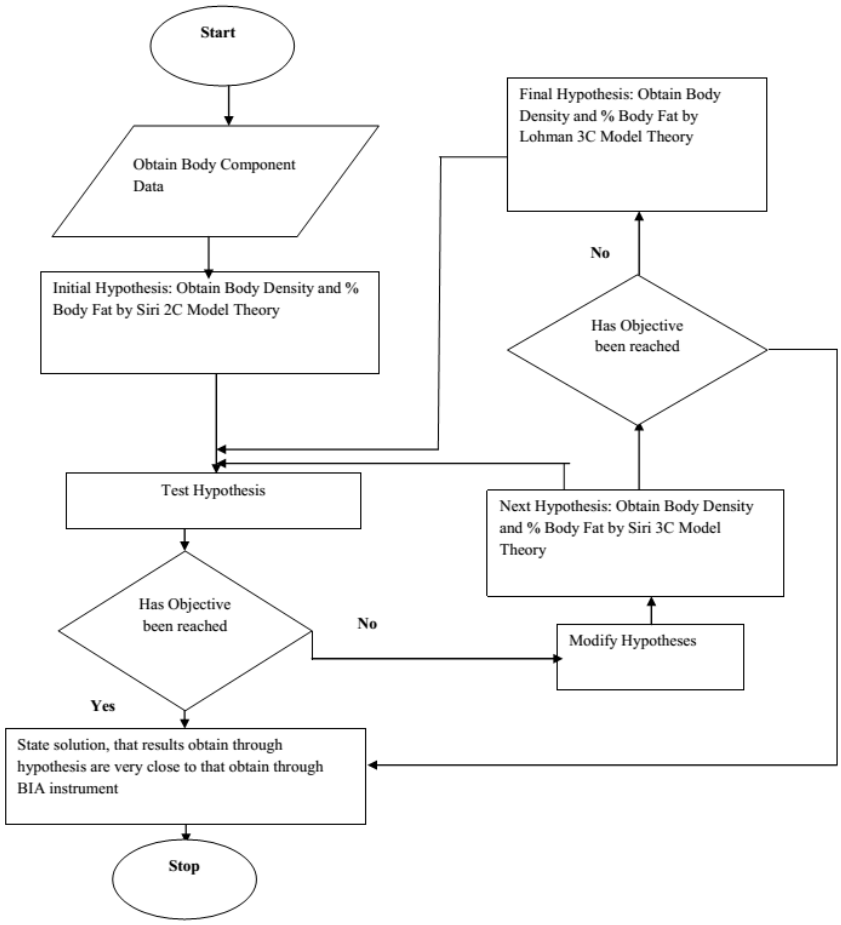


Fig2. *Flowchart showing the actual process while studying the comparative study of different body compartment models.*

Table1. *Characteristic component of the body composition of different parameter in Indian subjects (n = 70)*

S.No.	CostomerID	Sex	Age	Weight(Kg)	Db	%BF	%Mineral	%Protien
1	126	M	17	65	1.0683	13.35	0.071538	0.591077
2	131	M	18	66	1.0612	16.45	0.070606	0.563333
3	152	M	18	45	1.0671	13.89	0.05532	0.648889
4	138	M	18	48	1.0676	13.73	0.062083	0.62375
5	141	M	18	53	1.0717	11.89	0.069057	0.615472
6	75	M	19	82.5	1.0377	27.02	0.058182	0.505697
7	106	M	19	50	1.066	14.38	0.0624	0.6162
8	114	M	19	45	1.0681	13.51	0.052444	0.662444
9	120	M	19	52	1.0662	14.27	0.069231	0.590769
10	134	M	19	73	1.0588	17.51	0.06589	0.57137
11	139	M	19	52	1.0671	13.94	0.065577	0.607692
12	142	M	19	50	1.0695	12.84	0.0604	0.639
13	149	M	19	58	1.0595	17.21	0.068448	0.56431
14	154	M	19	48	1.0738	11.02	0.070208	0.619167
15	155	M	19	72	1.069	13.04	0.079167	0.564722
16	157	M	19	51	1.0656	14.59	0.061961	0.615098
17	158	M	19	63	1.0559	18.81	0.065238	0.560635
18	159	M	19	50	1.067	13.96	0.061212	0.6244
19	161	M	19	66	1.0561	18.73	0.065303	0.561212
20	153	M	19	82	1.041	25.51	0.06061	0.511707
21	59	M	20	56	1.0721	11.71	0.068036	0.620893
22	104	M	20	74	1.0454	23.5	0.062863	0.522838
23	62	M	20	60	1.0454	11.17	0.071	0.614833
24	121	M	20	69	1.0734	19.19	0.070288	0.537826

25	135	M	20	53	1.055	15.75	0.068679	0.578113
26	151	M	20	45	1.0629	9.71	0.057207	0.683556
27	99	M	20	59	1.0768	14.08	0.072712	0.578983
28	101	M	21	75	1.0667	24.43	0.058267	0.531333
29	109	M	21	63	1.0434	12.29	0.07254	0.597778
30	110	M	21	48	1.0708	12.98	0.05625	0.65375
31	AAA8	M	31	65	1.0531	20.05	0.06015	0.567692
32	AAA5	M	36	66	1.0421	25.05	0.05378	0.542576
33	AAA2	M	29	57	1.0602	16.95	0.06456	0.581754
34	AAA6	M	30	63	1.0519	20.63	0.07216	0.529048
35	AAA3	M	29	66	1.0456	23.45	0.063	0.522121
36	187	F	17	44	1.0656	14.52	0.089199	0.553409
37	127	F	17	50	1.046	23.24	0.071183	0.5244
38	173	F	17	45	1.0613	16.44	0.089481	0.262667
39	108	F	18	53	1.057	18.36	0.085545	0.52434
40	140	F	18	46	1.0653	14.72	0.089282	0.549565
41	167	F	18	62	1.04	25.95	0.074153	0.486935
42	169	F	18	52	1.046	23.27	0.079765	0.496346
43	171	F	18	39	1.0749	10.59	0.088398	0.596667
44	176	F	18	52	1.0393	26.33	0.072876	0.488269
45	183	F	18	57	1.0363	27.65	0.071352	0.480351
46	186	F	18	44	1.061	16.59	0.09186	0.524091
47	188	F	18	51	1.0463	23.14	0.076307	0.510588
48	189	F	18	39	1.067	14	0.090861	0.554872
49	190	F	18	43	1.0648	14.91	0.086215	0.558837
50	191	F	18	54	1.0396	26.19	0.077228	0.476481
51	192	F	18	50	1.062	16.12	0.092593	0.5248
52	193	F	18	58	1.0311	30.07	0.067525	0.468276
53	203	F	18	40	1.0584	17.68	0.083738	0.54
54	206	F	18	54	1.0336	28.89	0.071845	0.467037
55	195	F	18	57	1.0472	22.74	0.084008	0.502807
56	208	F	18	55	1.0367	27.49	0.072165	0.47
57	207	F	19	51	1.0365	27.55	0.068144	0.474706
58	115	F	19	50	1.0573	18.22	0.086152	0.5186
59	163	F	19	56	1.0469	22.88	0.091866	0.49125
60	164	F	19	63	1.0302	30.52	0.077077	0.462381
61	165	F	19	48	1.0535	19.85	0.065597	0.507292
62	168	F	19	57	1.0288	31.14	0.0742	0.47807
63	170	F	19	45	1.0462	23.2	0.05873	0.514
64	172	F	19	50	1.0528	20.24	0.090559	0.5216
65	177	F	19	56	1.0391	26.43	0.073086	0.514464
66	BB01	F	50	55	1.0238	33.51	0.05095	0.49
67	AAA1	F	34	56	1.0314	29.89	0.06396	0.481964
68	AAA4	F	36	58	1.02	35.31	0.048	0.481379
69	AAA7	F	23	48	1.0549	19.31	0.08021	0.529792
70	AAA0	F	27	44	1.0594	17.25	0.079	0.557727

Db is the density of body, Value of Sex for female=0 and for male=1

Table2. *Descriptive statistics of Indian subjects (n = 70)*

Variables	Mean ± S.D.
TBW	30.03186 ± 5.777168
FFM	43.6729 ± 7.679629
Weight	55.32143 ± 9.68191
%Mineral	0.071135 ± 0.011198
%Protein	0.544343 ± 0.064553
Age	20.68571 ± 5.604198
Body Density	1.054031±0.014017
% Body Fat (%BF)	19.58257 ± 6.310757
% Fat Free Mass (%FFM)	80.328184 ± 6.32163

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:

$$\frac{1}{\mathrm{Db}} = \frac{FM}{FM\mathrm{Db}} + \frac{\mathrm{FFM}}{\mathrm{FFMDb}}$$

Where Db is the density of body, FM Db is the Fat mass density of the body, FFM Db is the Fat Free Mass Density of the body. Now for Customer ID AAA2; FM=0.1695, FFM=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:

$$\%\mathrm{BF} = \frac{497.1}{\mathrm{Db}} - 451.9$$

For customer ID AAA2 Db = 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:

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

Where TBWDb is the Total Body Water density and constant density is assumed for minerals and proteins fractions as discussed earlier. Now for Customer ID AAA2 FM = 0.1695 TBW = 0.5817and Minerals = 0.06456, Proteins = 0.184.Putting all these values in the above equation, we get Db 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:

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

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 deviced 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:

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

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:

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

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% .

3. STATISTICAL ANALYSIS

The Prediction equation obtained for Body Density (Db) and %BF for different compartmental models using different parameters to obtain the Body Density and %BF. For 2C model the body density is obtained by linear regression model of Fat Mass (FM) and Fat Free Mass (FFM). And %Body Fat is obtained by the linear regression model of Body Density. And so, the Prediction equation developed are as follows.

$$2CDb = -0.128 \times FM + 0.04169 \times FFM + 1.04587 \quad (1)$$

$$2C\%BF = -432.184 \times 2CDb + 476.420 \quad (2)$$

Where 2CDb is the body density of 2C model, 2C%BF is the percentage of body fat in 2C model, FM and FFM are the Fat Mass and Fat Free Mass component of the body.

In a similar Pattern 3C water molecular level and 3C mineral molecular level Db and % BF prediction equation can be obtained.

$$3CWMDb = -0.8175 \times FM + 0.10242 \times TBW + 0.13052(M+P) + 0.98070 \quad (3)$$

$$3CWM\%BF = -157.707 \times 3CWMDb - 89.217 \times (TBW/BW) + 238.092 \quad (4)$$

Where 3CWMDb is 3C water molecular level body density, TBW is Total Body Water content. (M+P) is (Mineral +Protein) content, 3CWM%BF is 3C water molecular level %Body Fat and (TBW/BW) is (Total Body Water/Body weight) content of body.

For 3C Mineral molecular level prediction equation developed is as follows:

$$3CMMDb=-0.08369\times FM+0.15558\times M+0.10501\times (W+P)+0.98267 \quad (5)$$

$$3CMM\%BF=-483.74\times 3CMMDb+438.13\times (M/BW)+505 \quad (6)$$

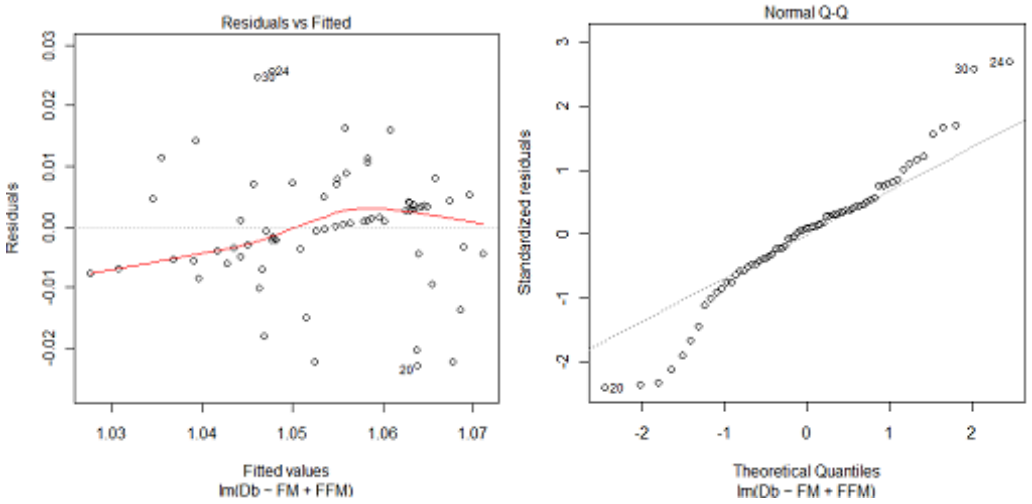
Where 3CMMDb is 3C mineral molecular level body density, M is Mineral content. (W+P) is (TBW +Protein) content, 3CMM%BF is 3C mineral molecular level %Body Fat and (M/BW) is (Mineral/Body weight) content of body.

Table3. *Descriptive statistics of Indian subjects (n=70) together with BIA equations developed.*

S.No.	Prediction Equations developed	Standard error	Residual error	MultipleR^2	Adjusted R^2
1.	2CDb = -0.128×FM+0.04169×FFM+1.04587	Intercept = 0.02615 FM=0.02721 FFM.=0.02729	0.009676 on 67 df	0.5373	0.5235
2.	2C%BF= -432.184×2CDb+476.420	Intercept = 6.05 2CDb=5.718	2.597 on 68 df	0.9882	0.9881
3.	3CWMDb=-0.8175×FM+0.10242×TBW+0.13052(M+P)+0.98070	Intercept = 0.01886 FM=0.02049 TBW=0.01936 (M+P)=0.03313	0.008128 on 66 df	0.6784	0.6638
4.	3CWM%BF=-157.707×3CWMDb-89.217×(TBW/BW)+238.092	Intercept = 5.844 3CWMDb=3.856 (TBW/BW)=4.76	2.254 on 67 df	0.9615	0.9604
5.	3CMMDb=-0.08369×FM+0.15558×M+0.10501×(W+P)+0.98267	Intercept = 0.0188 FM=0.02043 M.=0.0888 (W+P)= 0.01909	0.008157 on 66 df	0.6761	0.6614
6.	3CMM%BF=-483.74×3CMMDb+438.13×(M/BW) +505	Intercept = 11.41 3CMMDb=10.16 (M/BW)=67.17	6.215 on 67df	0.9713	0.9705

4. GRAPHICAL ANALYSIS

The graphical interpretation of data include scatter matrix plot, Residual vs Fitted, Normal Vs Fitted plot , Scale location plot and Residual vs Cook's plot for different models. The different graphs for Siri 2C model, Siri 3C model and Lohman 3C model are also shown. These graphs help in knowing the better picture of these models. Finally the table for calculating; Body density and % Body Fat by statistical model and Siri 2C, 3C and Lohman 3C model is shown in Tables given below. The results obtained through statistical regression model and that from Siri and Lohman model are very close to each other.



(a) **(b)**

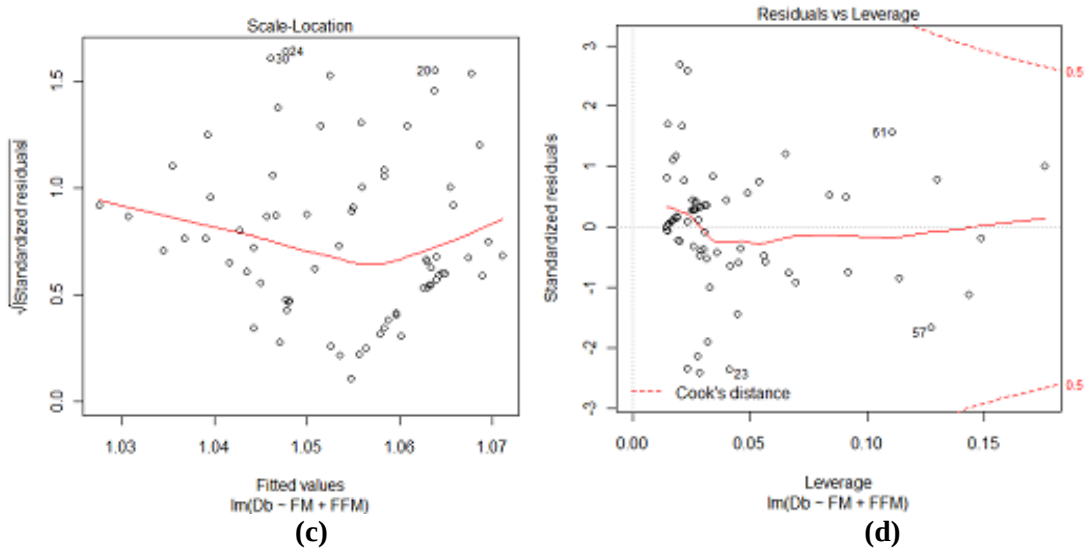


Fig3. *(a) shows Residual Vs Fitted Plot, (b) shows Normal Vs Fitted Plot, (c) shows Scale Location Plot and (d) shows Residual Vs Leverage plot of 2C Body Density formed by the linear combination of Fat Mass and Fat Free Mass.*

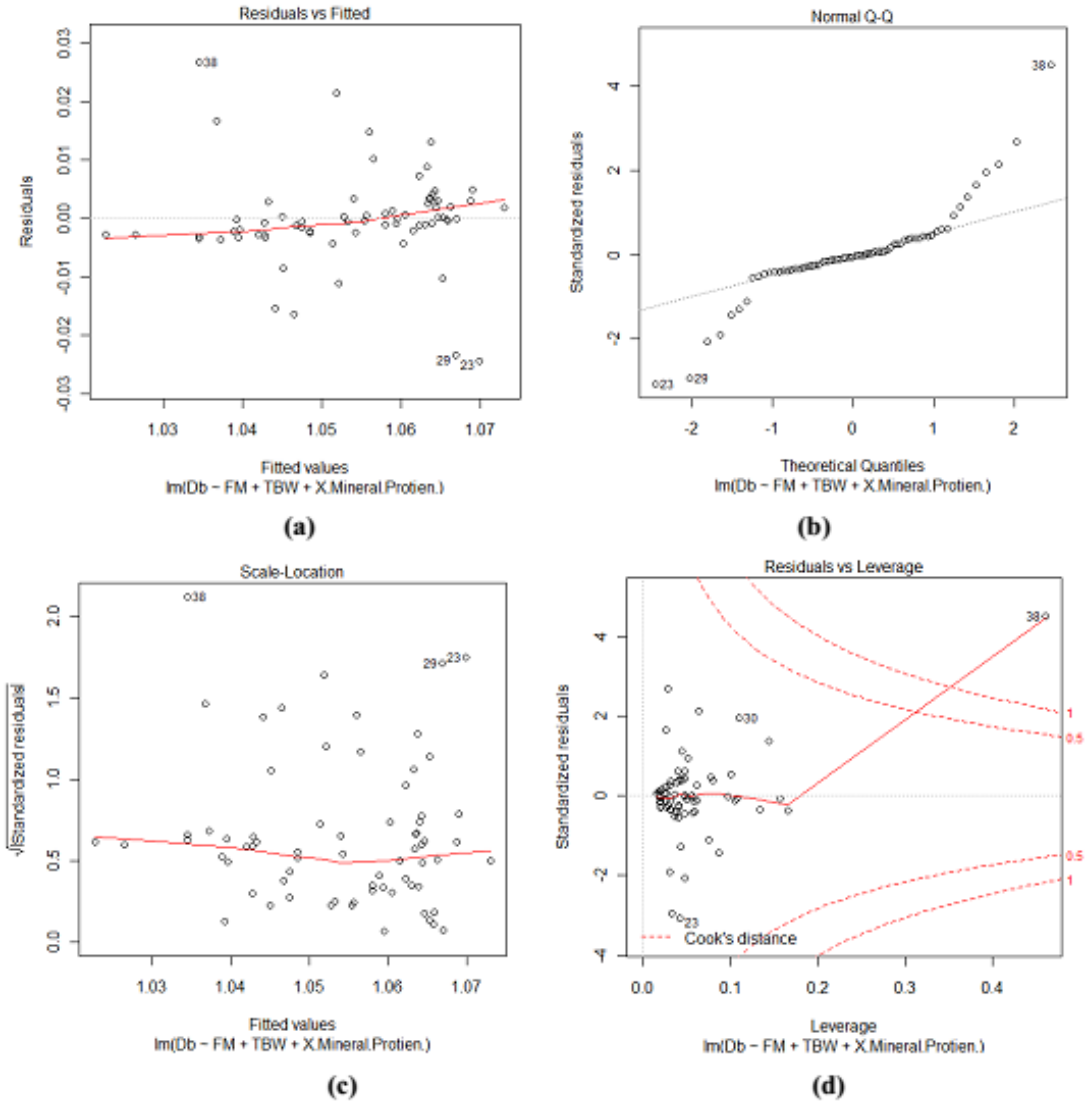


Fig4. *(a) shows Residual Vs Fitted Plot, (b) shows Normal Vs Fitted Plot, (c) shows Scale Location Plot and (d) shows Residual Vs Leverage plot of 3C Water Molecular Body Density formed by the linear combination of Fat Mass, Total Body Water and (Mineral+Protien) content.*

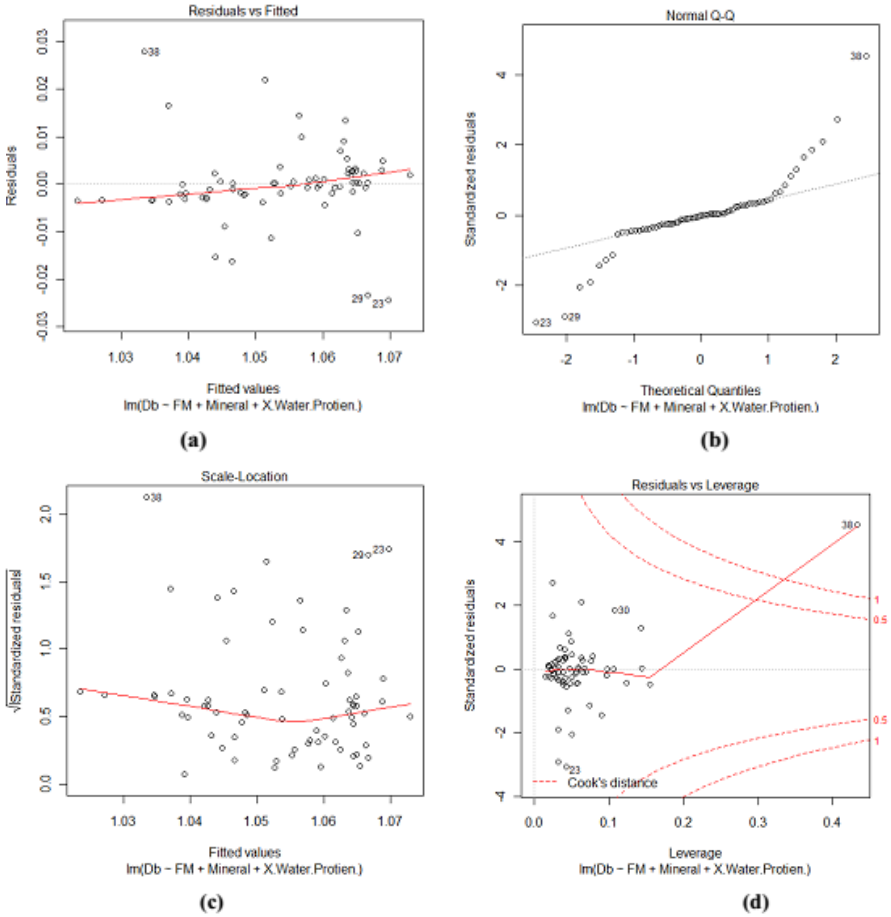


Fig5. *(a) shows Residual Vs Fitted Plot, (b) shows Normal Vs Fitted Plot, (c) shows Scale Location Plot and (d) shows Residual Vs Leverage plot of 3C Mineral Molecular Body Density formed by the linear combination of Fat Mass, Mineral and (Water +Protein) content.*

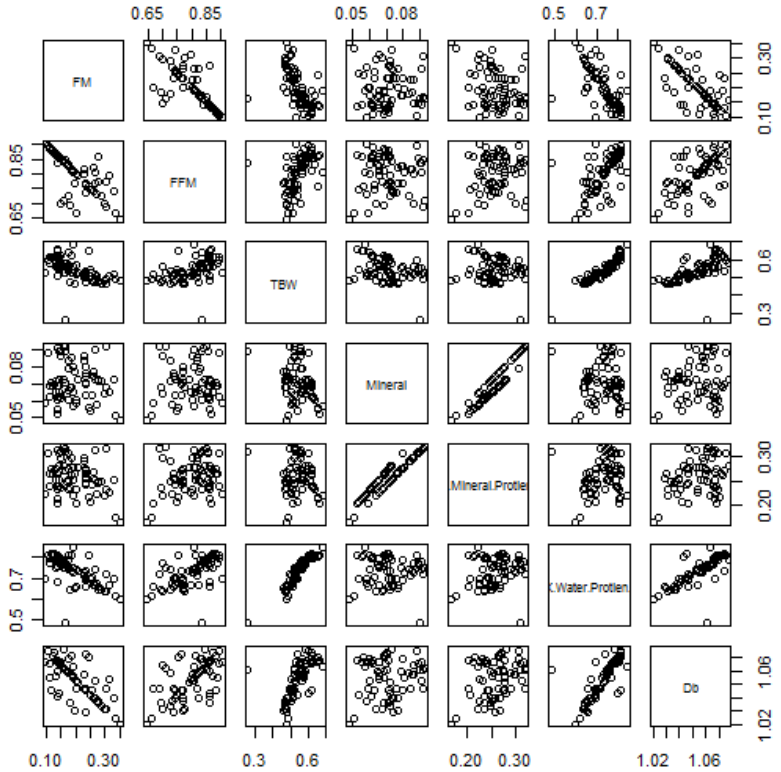


Fig6. *Scatter matrix Plot showing the actual process between different parameters and Body density while studying the comparative study of different body compartment models*

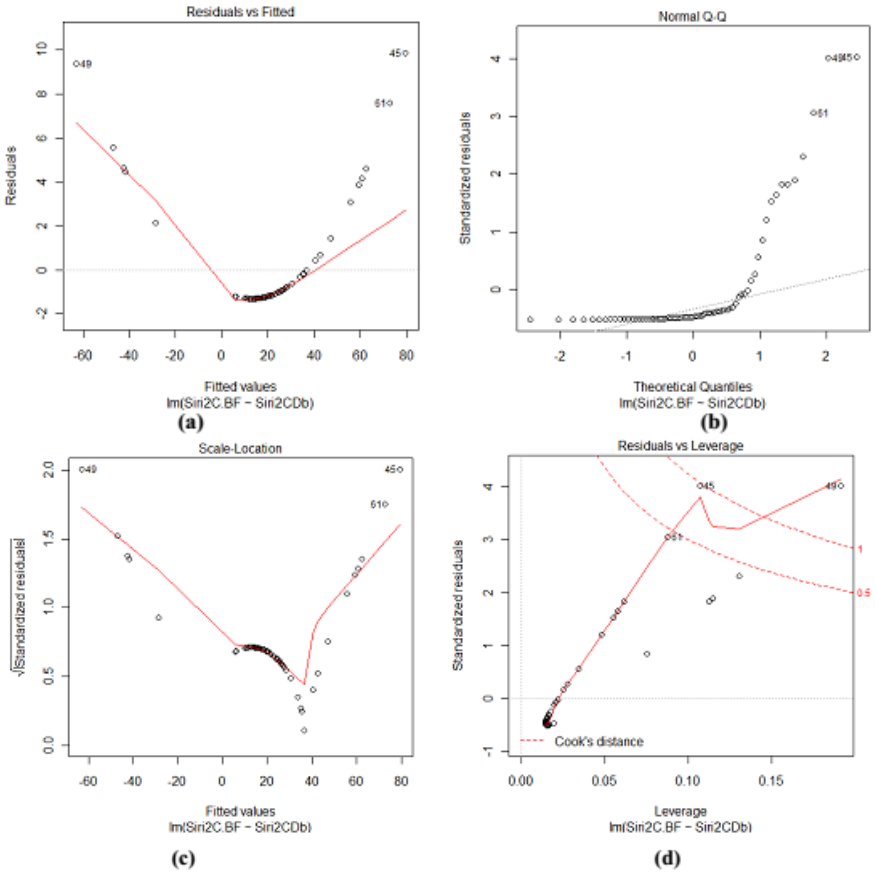


Fig7. *(a) shows Residual Vs Fitted Plot, (b) shows Normal Vs Fitted Plot, (c) shows Scale Location Plot and (d) shows Residual Vs Leverage plot of 2C %Body fat formed by the linear combination of 2C Body density.*

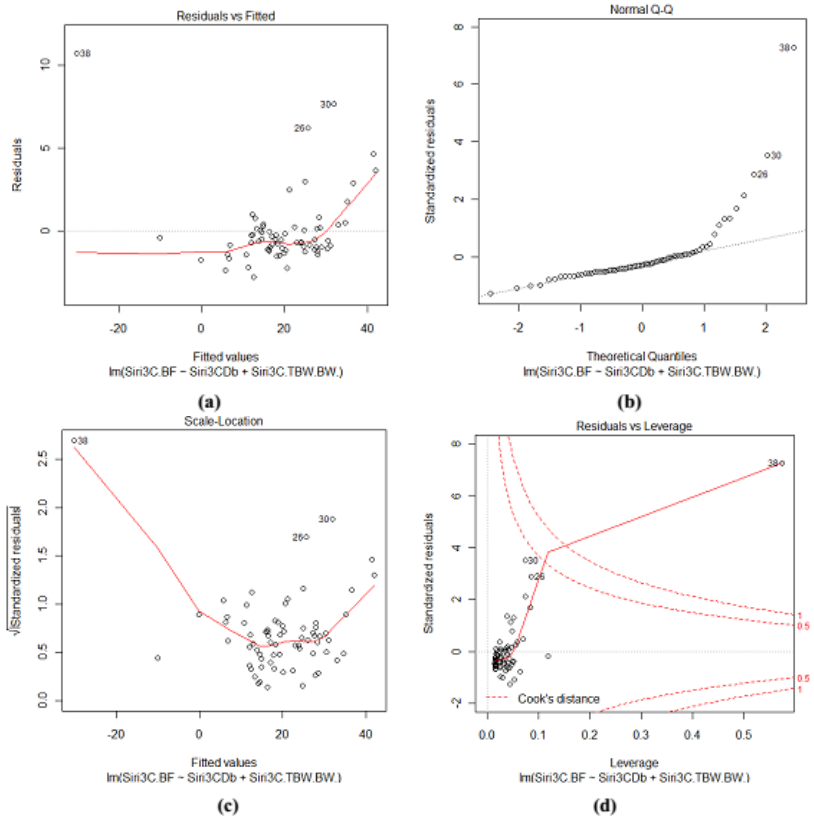


Fig8. *(a) shows Residual Vs Fitted Plot, (b) shows Normal Vs Fitted Plot, (c) shows Scale Location Plot and (d) shows Residual Vs Leverage plot of 3C %Body Density formed by the linear combination of 3C Body density and (TBW/BW) where TBW is Total Body Water and BW is Body weight of body.*

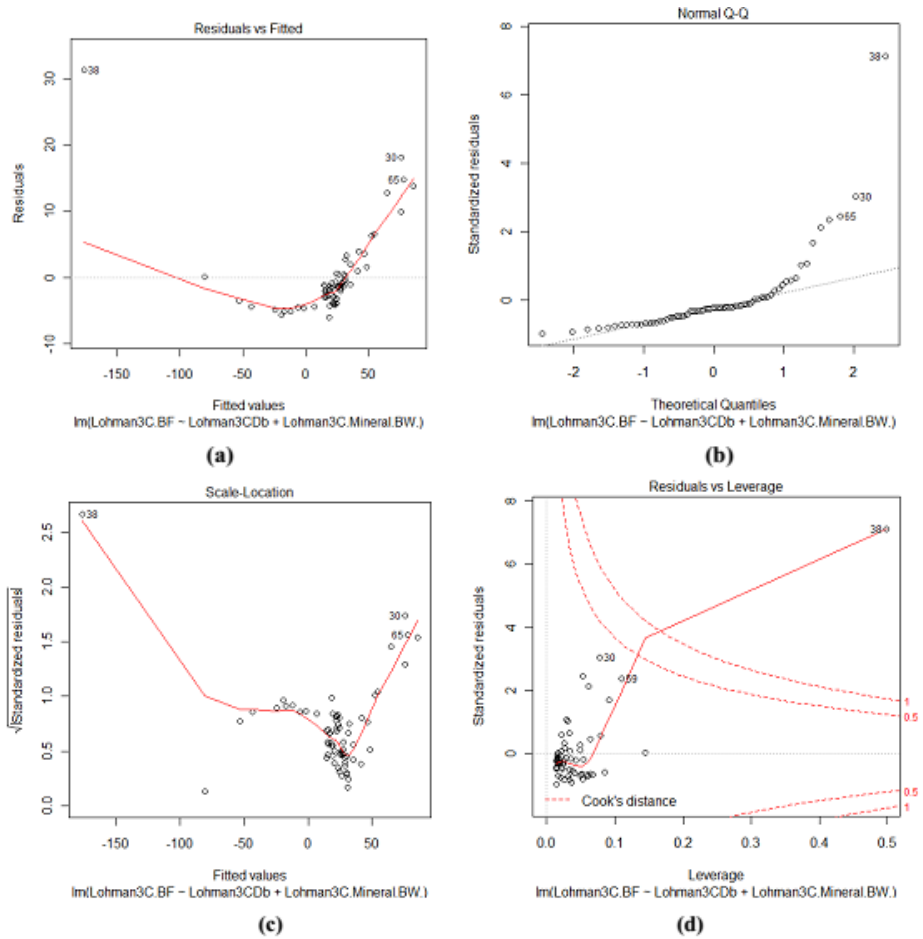


Fig9. *(a) shows Residual Vs Fitted Plot, (b) shows Normal Vs Fitted Plot, (c) shows Scale Location Plot and (d) shows Residual Vs Leverage plot of 3C %Body Density formed by the linear combination of 3C Body density and (M/BW) where M is Mineral content and BW is Body weight of body.*

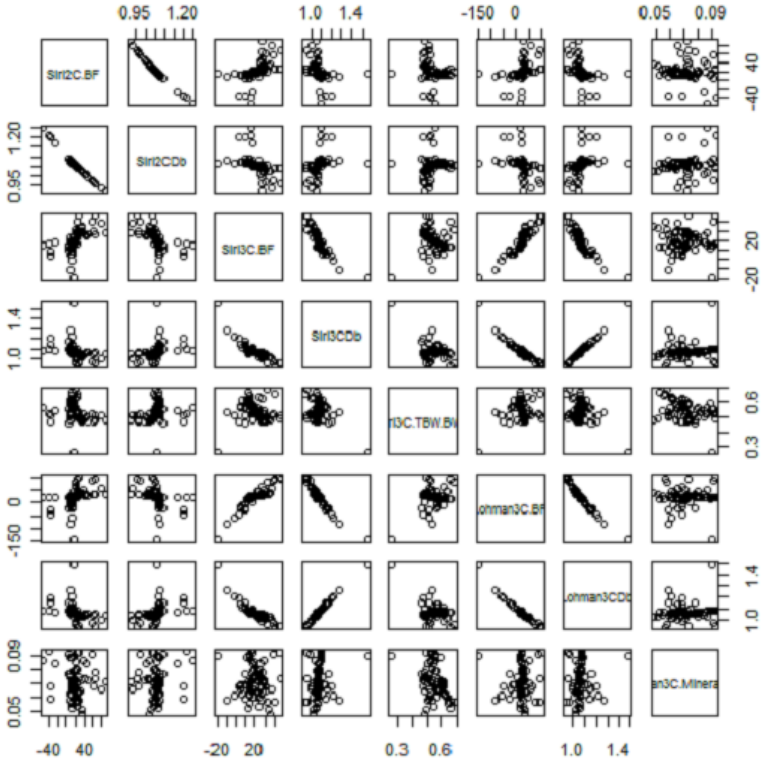


Fig10. *Scatter matrix Plot showing the actual process between different parameters and % Body Fat while studying the comparative study of different body compartment models.*

Table4. *Siri 2 Compartmental model of human body composition for calculating body density of 10 out of 70 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

Table5. *Siri 2 Compartmental model of human body composition for calculating %Body Fat of 10 out of 70 Indian subjects.*

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

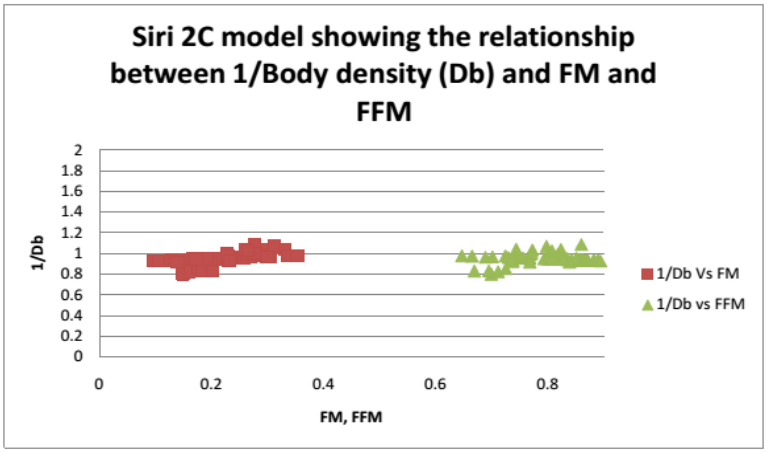


Fig11. *Siri 2 compartmental model of human body for (N=70)and various parameters used in Siri 2C equation for calculating 1/Db where (1/Db) is inverse of Body Density.*

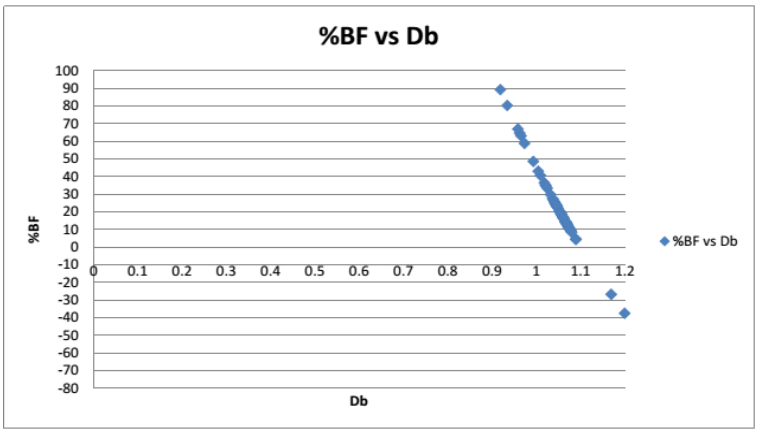


Fig12. *Curve pattern between % BF and Db of Siri 2C model, where % BF is the Body Fat percentage of subjects (N=70) and Db is the Body density measured through Experimental process of human body through Maltron-II BIA Analyzer.*

Table6. *Siri 3 Compartmental model of human body composition for calculating body density of 10 out of 70 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

Table7. *Siri 3 Compartmental model of human body composition for calculating %Body Fat of 10 out of 70 Indian subjects*

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

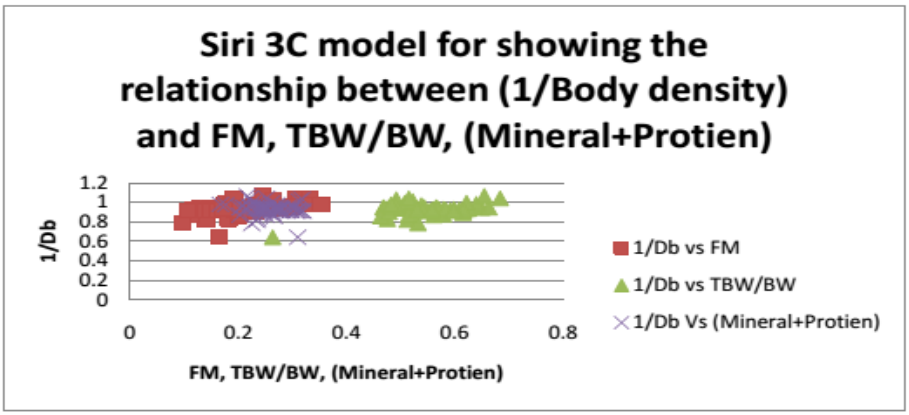


Fig13. *Siri 3 compartmental model of human body for (N=70) and various parameters used in Siri 3C equation for calculating 1/Db where (1/Db) is inverse of Body Density.*

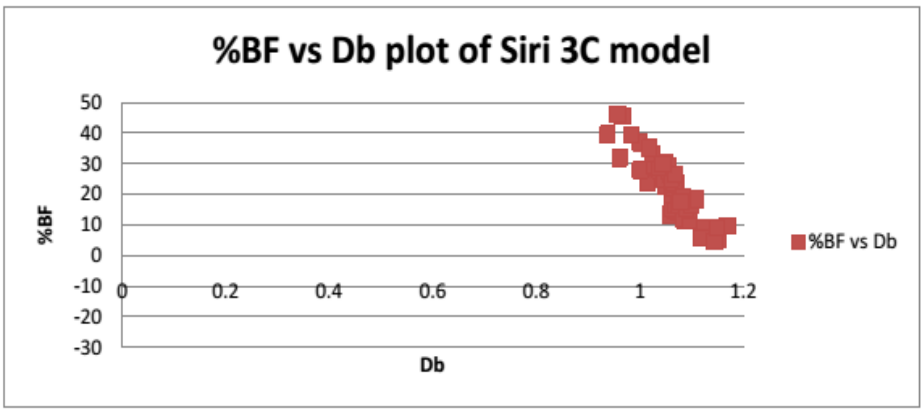


Fig14. *Curve pattern between % BF and Db of Siri 3C model, where % BF is the Body Fat percentage of subjects (N=70) and Db is the Body density measured through Experimental process of human body through Maltron-II BIA Analyzer.*

Table8. *Lohman 3 Compartmental model of human body composition for calculating body density of 10 out of 70 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

Table9. *Lohman 3 Compartmental model of human body composition for calculating % Body Fat of 10 out of 70 Indian subjects.*

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

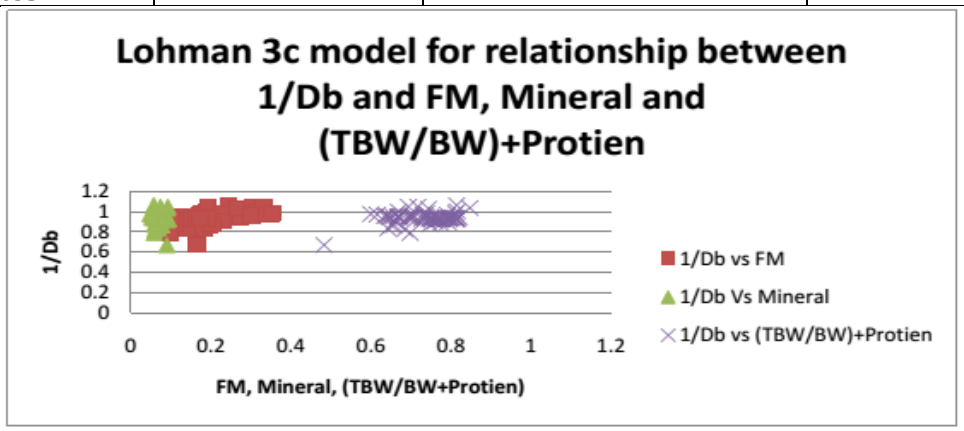


Fig15. *Lohman 3 compartmental model of human body for (N=70) and various parameters used in Lohman 3C equation for calculating 1/Db where (1/Db) is inverse of Body Density.*

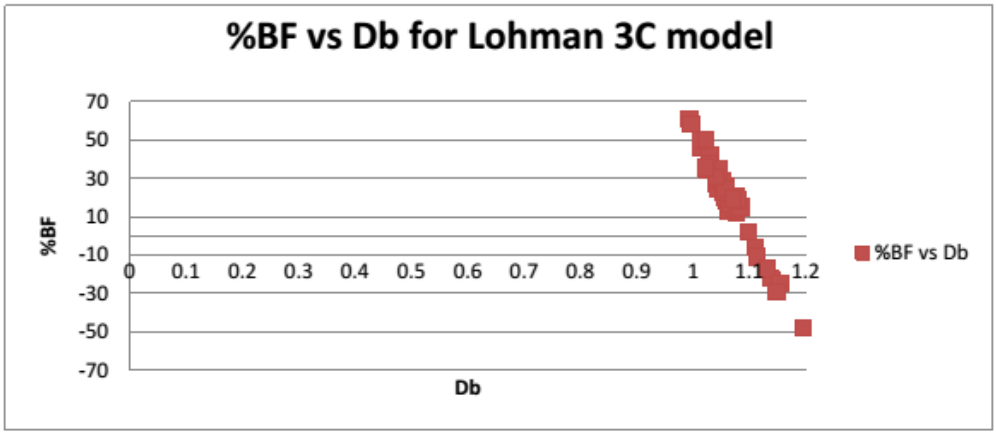


Fig16. *Curve pattern between % BF and Db of Lohman 3C model, where % BF is the Body Fat percentage of subjects (N=70) and Db is the Body density measured through Experimental process of human body through Maltron-II BIA Analyzer.*

Table10. *The comparative study showing the measured and obtained Body Density(Db) of the subject(N=70) through different compartment models like Statistical 2C model, Statistical Water Molecular level 3C model, Statistical Mineral Molecular level 3C model, Siri 2C Model, Siri 3C Model and Lohman's 3C models. different body compartment models.*

Siri2CDb	Statistical 2CDb	Siri3CDb	StatisticalW3CDb	Lohman3CDb	StatisticalM3CDb
1.068438	1.064906	1.088247	1.066247593	1.075616	1.066086056
1.061367	1.059646	1.083044	1.06044621	1.069368	1.060188715
1.0672	1.06399	1.060228	1.063579293	1.062223	1.064329359
1.067567	1.064262	1.072159	1.06452185	1.068157	1.064890042
1.071802	1.067384	1.085761	1.068665902	1.076429	1.068719317
1.037944	1.04171	1.050395	1.039641114	1.042174	1.039624695
1.066078	1.063159	1.071679	1.063380354	1.067005	1.063700508
1.068071	1.064635	1.057245	1.063897179	1.061757	1.064814243
1.06633	1.063345	1.083264	1.06430436	1.072284	1.064234124
1.05897	1.057847	1.073734	1.057982263	1.064029	1.057959632
1.06633	1.063345	1.073604	1.064255521	1.066111	1.06439265
1.048873	1.058264	1.014246	1.062164803	1.012455	1.062576023
1.067085	1.063905	1.122342	1.061485984	1.109364	1.061387976
1.069611	1.065772	1.0656	1.068913133	1.055894	1.068889785
1.059648	1.058356	1.048123	1.064242019	1.030097	1.06357077
1.073816	1.06886	1.118631	1.065860738	1.113586	1.066251023
1.069151	1.065432	1.150192	1.060235051	1.138745	1.060297365
1.065599	1.062802	1.062649	1.063506496	1.05917	1.063889687
1.056046	1.055641	1.070297	1.055629928	1.060315	1.055574776
1.06704	1.063871	1.221217	1.05211429	1.208636	1.052258749
1.056225	1.055777	0.999946	1.063148343	0.992821	1.063125506
1.041226	1.044272	1.037248	1.044996806	1.027247	1.044828446
1.072218	1.067689	1.08296	1.069773772	1.072186	1.069726753
1.045628	1.047683	1.025524	1.0519039	1.012082	1.051460002
1.073468	1.068606	1.143406	1.065255861	1.130771	1.065241095
1.055194	1.054996	0.959937	1.063780085	0.962159	1.0644204
1.062956	1.060834	1.067884	1.063669419	1.054154	1.063367674
1.076863	1.071083	1.272575	1.05645252	1.262629	1.056835802
1.066765	1.063668	1.068037	1.066856013	1.055564	1.066646883
1.043587	1.046105	0.936937	1.0559105	0.938277	1.056427796
1.053271	1.053537	1.061667	1.052687129	1.055591	1.052870876
1.04223	1.045053	1.045719	1.042785075	1.042551	1.043118308
1.060235	1.058798	1.072439	1.05886871	1.064168	1.058940658
1.052079	1.052549	1.065117	1.054260215	1.048988	1.053766251
1.045838	1.047764	1.062636	1.04672164	1.05189	1.046575983
1.065759	1.062921	1.093146	1.06568172	1.079003	1.065462625
1.046201	1.048124	1.060733	1.047479468	1.054876	1.047688657
1.06139	1.059663	1.552115	1.034489496	1.488564	1.033464068
1.057056	1.056405	1.086652	1.057948928	1.072772	1.057711196
1.065302	1.062582	1.0949	1.065161683	1.080432	1.064925696
1.040268	1.043525	1.061876	1.042774841	1.052263	1.042721143
1.046134	1.048073	1.070964	1.048440634	1.058879	1.048256361
1.074814	1.06959	1.095456	1.072951402	1.084396	1.072953096
1.009025	1.044211	1.058836	1.04201722	1.050027	1.042009112
0.918441	1.046331	1.055019	1.039459178	1.046538	1.039458446
1.04413	1.060109	1.093919	1.062186871	1.07653	1.061751727
1.077689	1.047022	1.064936	1.048452382	1.055582	1.04843619
1.089348	1.06292	1.094194	1.066956257	1.079358	1.066698375
1.248026	1.055939	1.089496	1.064544577	1.077459	1.064449696
0.962252	1.04667	1.063108	1.04288967	1.0513	1.042689713
1.211495	1.054882	1.097551	1.062945884	1.079775	1.062499661
0.965051	1.03959	1.04822	1.034493883	1.041139	1.034563473
1.168943	1.053469	1.081809	1.059273247	1.070007	1.059161158
1.021047	1.039095	1.053718	1.037245649	1.044396	1.037179285

1.004092	1.050857	1.059935	1.051394179	1.046461	1.051088233
0.992994	1.042761	1.066	1.038840878	1.05633	1.038785993
1.199151	1.051515	1.204502	1.045108176	1.195274	1.045403152
1.017645	1.049998	1.03522	1.053934209	1.02202	1.053572186
1.036433	1.035512	0.965421	1.047448759	0.950261	1.046655992
1.088653	1.05248	1.168724	1.046541691	1.153633	1.04643752
0.933862	1.039263	0.999159	1.036736947	0.995658	1.036960986
1.079452	1.046845	1.108439	1.044093257	1.097505	1.044076615
1.200892	1.047845	1.147518	1.043244422	1.147512	1.043953993
0.973208	1.045704	0.982477	1.053264463	0.968951	1.052687949
0.958033	1.034481	0.95558	1.039211549	0.949625	1.039138024
1.024067	1.030697	1.022936	1.026456369	1.025314	1.027133432
1.03179	1.036838	1.043844	1.034454354	1.039327	1.034693094
1.020284	1.027642	1.017781	1.022803264	1.021004	1.023527722
1.054925	1.054793	1.081766	1.055304579	1.071219	1.055266922
1.059557	1.058288	1.078045	1.059430824	1.069541	1.059526182

Table11. *The comparative study showing the measured and obtained %Body Fat(BF) of the subject (N=70)through different compartment models like Statistical 2C model, Statistical Water Molecular level 3C model, Statistical Mineral Molecular level 3C model, Siri 2C Model, Siri 3C Model and Lohman's 3C models. Different body compartment models.*

Siri2C%BF	Statistical2C%BF	Siri3C%BF	StatisticalW3C%BF	Lohman3C%BF	StatisticalM3C%BF
13.35863	16.18449891	13.12093	17.20318093	13.04269	20.63467754
16.45826	18.4579553	16.21992	20.59329958	12.67336	23.07894449
13.89835	16.58052034	13.75502	12.46618037	14.10432	14.37871055
13.73822	16.46318066	13.49283	14.56034885	13.4434	17.07066184
11.89835	15.11377428	11.66376	14.64536805	11.61121	18.27348717
27.02757	26.20970822	26.79407	29.01655235	26.80338	27.58314988
14.38858	16.93987313	14.17021	15.41395911	14.2143	17.78482826
13.5185	16.30183859	13.26133	11.20666152	13.22913	12.88424243
14.27839	16.85920209	14.04021	17.5370939	13.97349	20.519462
17.5184	19.23533071	17.28871	20.26488623	17.2708	22.09117352
14.27839	16.85920209	14.47944	16.03496991	15.97456	18.84191657
22.03726	19.0551532	23.58308	13.57151241	45.66852	17.45252663
13.94855	16.61718899	9.296325	20.34215381	-6.24249	21.55342356
12.8484	15.81047866	15.06626	14.27672398	23.60508	18.69563237
17.21805	19.0153188	22.62719	19.87076134	42.29953	25.19356717
11.02847	14.47573975	5.960928	15.12109879	-10.9947	16.35860867
13.04836	15.95715327	5.013645	20.86734513	-22.3664	20.67451919
14.59819	17.09388146	15.21003	14.66248631	18.1711	17.17292242
18.81813	20.18871565	18.71445	21.54210912	19.14038	22.98747445
13.9682	16.63185645	-1.87962	26.51321992	-56.6283	22.53530512
18.73836	20.1300458	27.98179	15.03186626	61.16661	20.5321553
25.51797	25.10231495	28.01282	26.6426654	37.56175	27.11699505
11.71841	14.98176714	12.21809	14.52760229	14.72871	18.63761067
23.50808	23.62823516	29.17813	24.21616166	49.81744	27.16181839
11.17855	14.5857457	4.74321	18.51616792	-17.0487	19.79071048
19.19821	20.4673974	31.92215	9.341658179	77.37524	15.16124899
15.75812	17.94459418	17.77547	18.68875608	25.59501	22.46377046
9.718609	13.51502108	-10.4098	24.07807638	-80.1505	19.29462365
14.08829	16.71986122	16.28107	16.50939881	24.7176	20.80204797
24.43786	24.31027207	39.66325	13.24190903	93.88987	18.6084307
20.05831	21.0980982	19.81758	21.42806631	19.79457	22.03776183
25.05806	24.76496335	24.81916	25.23051277	24.83824	23.96458109
16.95832	18.82464181	16.71691	19.19861123	16.66543	21.03371896
20.59304	21.52525634	22.18568	24.62774279	28.3598	26.86657441
23.41262	23.59336828	23.19021	26.43458221	23.052	26.33152375
14.52815	17.04254535	15.1868	20.65303413	18.17422	28.67369508
23.2477	23.43755817	23.37004	26.11176069	24.5748	29.37850278
16.44811	18.45062157	-19.429	51.51143303	-144.553	44.27634717

18.36837	19.85869778	18.61212	24.46604031	20.1647	30.82268676
14.72824	17.18921996	15.17624	21.07798649	17.42438	28.96986458
25.95763	25.42499908	26.07735	30.19618506	27.25432	33.0825276
23.27813	23.45955936	23.65075	28.46305811	25.6857	32.86408075
10.59863	14.16038934	11.40414	15.64724327	14.91362	24.69939325
40.7538	25.12891457	26.54598	30.19667428	28.04105	32.8677053
89.34326	24.21231022	27.88731	31.30654723	29.46505	33.43396029
24.19014	18.2579293	17.33671	23.81987657	20.58816	31.63504517
9.364799	23.91376227	23.65931	27.19056962	26.19945	31.26178876
4.428005	17.04316769	14.88714	20.32153264	18.63812	28.80434836
-53.591	20.06005188	15.41251	20.34808916	17.84055	27.85651013
64.70064	24.06589622	26.66162	31.11075053	29.02846	34.44522405
-41.5805	20.51680899	16.64069	23.63691183	19.09543	31.59400641
63.20231	27.12579481	30.1313	33.16690562	31.11345	34.12509699
-26.644	21.12754549	18.26317	22.86001406	20.98697	29.32931626
34.9532	27.33967792	29.17366	32.84345705	30.91171	34.75235344
43.17416	22.25646931	25.20463	27.42084457	34.52298	33.3531292
48.70725	25.75516518	26.62668	32.32753172	24.13046	34.11529243
-37.3567	21.97220893	3.413247	30.91929025	-47.7373	29.15262918
36.58076	22.62760602	28.74339	25.61126145	49.96581	33.0907706
27.72579	28.88822388	45.66865	29.07414725	99.41388	38.93972396
4.719327	21.55501825	9.757569	31.79280813	-24.9142	32.5660143
80.40563	27.26727025	37.00952	29.33228572	58.36804	32.12069653
8.611445	23.9901966	18.39005	30.77919795	2.25602	32.44781111
-37.9577	23.5581254	9.080268	27.70751388	-29.2289	25.72889291
58.88495	24.48334361	39.49277	25.44923408	85.93376	35.44943498
66.97565	29.33375415	46.11728	28.3021041	92.42547	34.34868113
33.51746	30.96929918	33.43108	32.49631541	34.01489	30.4571971
29.88408	28.31502935	29.91067	31.95189946	30.77063	32.50035729
35.31728	32.28937064	35.15219	33.84154772	35.47558	30.90893958
19.31833	20.55540216	19.06721	24.39665768	18.91445	29.66758659
17.25834	19.04465372	17.56403	21.25358891	19.37046	27.07707476

5. 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 Statistical Analysis, i.e. Statistical 2Cmodel, Statistical water molecular level 3C model and Statistical mineral molecular level 3C model. The comparative study of the results is shown in Table 10 and Table 11. The results obtained by Statistical water molecular level 3C model and Statistical mineral molecular level 3C model slightly overestimates the results obtained from Siri 3C model and Lohman 3C 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.

6. 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 70 subjects volunteered for the study and we have compared Siri 2C model, Siri 3C model and Lohman 3C model with Statisical models developed. 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 and Siri formulated the following equation to calculate Human Body Density in its 3C model.

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

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

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. 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 Statical results.

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