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Estimation of Fat Free Mass Index by New Mathematical Model Development Based on Bioelectrical Impedance Analysis

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Abstract:- This paper proposed new mathematical models for the estimation of fat free mass index directly from the bioelectrical impedance analysis to detect different types of diseases. To develop model, multivariate regression algorithm has been applied on the database of National Health and Nutrition Examination Survey (NHANES). In the database there are 2900 people's data from which 1500 data have been used for the model development and validated over the remaining data. The correlation coefficients are 0.98 for both male and female model which is close to unity. The other elements of statistical analysis also show better performance of the proposed models comparing recent models and hence the new developed models can be a good alternative solution for the diseases detection scheme.

Keywords:- *Bioelectrical Impedance, Body Composition, DXA, Fat Free Mass Index, Multivariate Regression Analysis.*

I. INTRODUCTION

To determine the health condition of any human being, body composition is one of the major indicator. Among the different elements of body composition, fat free mass (FFM) is one of the most important element as it is related with body fat distribution. The concept of free mass index (FFMI) is derived from fat free mass. The ratio of fat free mass in to the square of the height of human body is defined as fat free mass index. The physical structure and composition of human body is so much variable and hence the simple measurement of fat free mass is not sufficient to detect any disease as the limit of FFM cannot be determined in universal way. The normal value of FFMI is 18 kg/m^2 to 20 kg/m^2 for male and 15 kg/m^2 to 16.5 kg/m^2 for female [1]. To detect some major diseases like cardiac diseases, eating disorder, chronic obstructive pulmonary diseases (COPD), end stage kidney failure have great impact on fat free mass index [2]-[5].

FFMI is measured from the FFM. The conventional method to measure FFM is dual energy X-ray Absorptiometry (DXA) which is costly and required complex arrangement and precautions that cannot be arranged easily. The alternative method for measuring FFM is bioelectrical impedance analysis. There are many regression analysis based mathematical models to measure FFM using bioelectrical impedance analysis though the accuracy is not still satisfactory. In this paper, two new mathematical models (one for male and another for female) have been developed to estimate FFMI in which bioelectrical impedance at 50 kHz frequency along with age, weight, height, body mass index (BMI) have been considered and compared few recent models.

II. MATERIALS AND METHODS

A. Subjects

To propose mathematical models for FFMI estimation, total 2900 people's data have been considered from the data base of the National Health and Nutrition Examination Survey (NHANES), USA [6]. Among them, 1450 data of male and 1450 data of female population have been used in which 750 data of each gender have been utilized for model development. Rest of 700 male data and 700 female data have been used for model validations. The general characteristics data are summarized in the following tables.

Parameters	**Male (n = 750)**	**Female (n = 750)**
	Mean **±** ***SD***	***Mean*** **±** ***SD***
Age (years)	21.26 ± 11.19	20.91 ± 11.49
Weight (kg)	69.70 ± 22.85	63.32 ± 21.73
Height (cm)	167.52 ± 14.83	157.13 ± 10.59
Height (m)	1.67 ± 1.48	1.57 ± 0.11
BMI (kg/m^2)	24.23 ± 5.77	25.20 ± 7.11
Z_{50} (Ω)	517.73 ± 92.48	599.91 ± 87.37
FFMI (kg/m^2)	18.34 ± 3.91	15.56 ± 3.20

Table 1:- General Characteristics of Data Used in Model Development

Parameters	**Male (n = 700)**	**Female (n = 700)**
	Mean **±** ***SD***	***Mean*** **±** ***SD***
Age (years)	21.18 ± 10.84	21.46 ± 11.28
Weight (kg)	68.76 ± 22.20	62.95 ± 19.86
Height (cm)	167.54 ± 14.99	158.20 ± 10.00
Height (m)	1.68 ± 0.15	1.58 ± 0.10
BMI (kg/m^2)	23.86 ± 5.40	24.79 ± 6.56
Z_{50} (Ω)	519.84 ± 90.71	608.95 ± 90.73
FFMI (kg/m^2)	18.29 ± 3.67	15.42 ± 3.11

Table 2:- General Characteristics of Data Used in Model Validation

B. Dual Energy X-Ray Absorptiometry (DXA)

Dual energy X-ray absorptiometry (DXA) is one of the most common method for the measurement of bone mineral density and from the body fat distribution is predicted. The difference between conventional X-ray and DXA is in the number of ray sent for image collection. In DXA, two different energy levels X-ray are sent through the body in which first ray is stronger than second ray and from the T-scoring of two images, body fat distribution is measured [7]. Considering body weight and height, the FFMI can be estimated from body fat information through DXA.

C. Bioelectrical Impedance Analysis (BIA)

The electrical impedance generated in the body tissues due to the current flow and voltage drop is called bioelectrical impedance. It is a tetra electrodes based method in which current is sent though two electrodes and voltage drop is measured through another two electrodes. The electrodes are set up on the right hand and the right foots [8].

D. Recent Mathematical Models of FFM Based on BIA

Various types mathematical models of FFM were developed based on BIA. Among them most recent few models have been chosen for the comparison. As there is no any direct mathematical model for FFMI estimation, the results, found from the proposed models have been compared with estimated FFMI by recent models. All the results of the recent models were compared with the DXA results. Aglago *et al*. [9] developed a mathematical models for FFM measurement considering 250 people's data (194 male and 56 female). The data of bioelectrical impedance analysis at 50 kHz frequency. The limitations of this model are insufficient number of data was used for model development and the inapplicable for common use as the accuracy was not good. The model equation has been showed in equation 1.

Kafri *et al*. [10] showed four models of FFM at four different frequencies such as 5, 50, 100 and 200 kHz considering 90 patient's data. The major drawbacks were that there was no any mathematical models which was used to estimate as well as the number of data was so short.

Later Hofsteenge *et al*. [11] proposed another model to estimate FFM considering 103 people's data using height, weight and bioelectrical impedance at 50 kHz frequency data. This model had also similar type of shortcomings like previous ones. The model equation has been stated in equation 2.

$$FFM\ (kg) = 7.47 + 0.31w - 0.06a + 0.37h^2/R_{50} + 6.04s \quad (1)$$

$$FFM\ (kg) = -1.87 + 0.53h^2/Z_{50} + 0.31w \quad (2)$$

$$FFMI\ (kg/m^2) = FFM / h^2 \quad (3)$$

Where, h = height of the patient in cm, w = weight of the patient in kg, a = age in years, Z_{50} = bioelectrical impedance in Ω at 50 kHz frequency, R_{50} = resistance in Ω at 50 kHz frequency in Ω and s = sex (0 for male 1 for female).

E. Statistical Analysis

To propose any model, different types of statistical analysis are required. The correlation (Pearson) coefficient, 95% limit of agreement with Bland Altman Plot [12], bias, absolute error and root mean square error (RMSE) have been considered in this paper to validate proposed models.

III. RESULTS

A. Proposed Mathematical Models for FFMI Estimation

The Two separate models (one for male and one for female) to estimate FFMI have been proposed considering age, weight, height, body mass index, bioelectrical impedance at 50 kHz frequency and impedance index. The proposed model equations have been given below.

$$FFMI\ (Male,\ kg/m^2) = 4.312 + 0.09a - 0.186w + 0.772b - 0.007Z_{50} + 2079.79\ h^2/Z_{50} \quad (4)$$

$$FFMI\ (Female,\ kg/m^2) = 5.46 - 0.002a - 0.161w + 0.613b - 0.006Z_{50} + 2063.43\ h^2/Z_{50} \quad (5)$$

Where, a = age in years, b = BMI in kg/m^2, h = height in m, w = weight in kg, Z_{50} = bioelectrical impedance at 5 kHz frequency in Ω.

B. Statistical Evaluation of Proposed Models

From the statistical analysis it is seen that the correlation coefficients for both models are 0.98 which are very closer to unity. It indicates excellent matching with the actual results. The 95% LOA -1.08 kg/m^2 to 0.09 kg/m^2 for male and -1.04 kg/m^2 to 0.72 kg/m^2 for female. Bias for male is only 0.04 kg/m^2 and for female -0.16 kg/m^2. The absolute errors are 0.45 ± 0.28 kg/m^2 for male and 0.41 ± 0.24 kg/m^2 for female. The values of RMSE are 0.53 kg/m^2 and 0.48 kg/m^2 for male and female respectively.

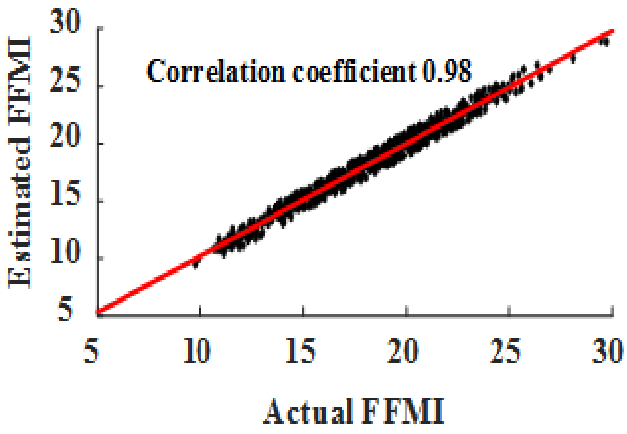

Fig 1:- Correlation Curve (Male)

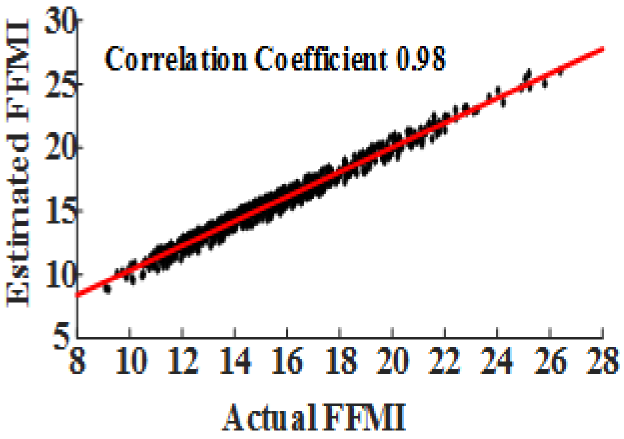

Fig 2:- Correlation Curve (Female)

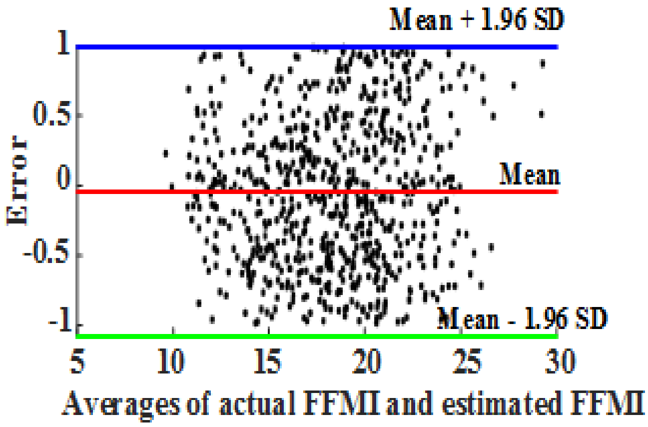

Fig 3:- Bland-Altman Plot (Male)

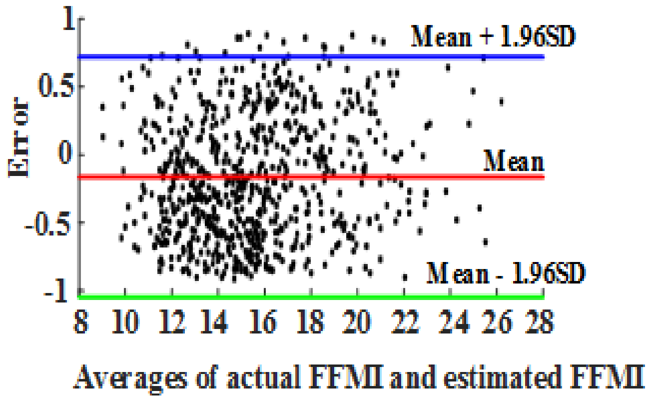

Fig 4:- Bland-Altman Plot (Female)

Fig.1 and 2 show the correlation curve from which it is seen both curves exhibit linear relationship between actual and estimated values of FFMI with positive covariance. Fig. 3 and 4 show the Bland-Altman plot in which all the errors with respect to the averages of actual and estimated values of FFMI are present within the interval of the 95% LOA.

IV. DISCUSSION

Multivariate regression analysis is one of the major algorithms in machine learning. To propose the mathematical models for the estimation of FFMI, multivariate regression analysis has been chosen as the accuracy of this algorithm is much better than other conventional algorithms in machine learning. To prove the robustness of the proposed models, the results have been compared with recent models by statistical analysis. The overall comparison results have been stated in the Table 3 and Table 4.

Model	Correlation (Pearson) coefficients	Bias (kg/m^2)	Absolute errors (mean ± SD) (kg/m^2)	95% LOA (kg/m^2)	RMSE
Aglago *et al.* [9], 2013	0.92	-0.97	1.63 ± 1.59	[-5.00 to 3.07]	2.28
Hofsteenge *et al.* [11], 2015	0.92	1.00	1.06 ± 0.69	[-0.50 to 2.52]	1.27
Proposed	**0.98**	**0.04**	**0.45 ± 0.28**	**[-1.08 to 0.99]**	**0.53**

Table 3:- Statistical Comparison of Proposed and Current Models (Male)

Model	Correlation (Pearson) coefficients	Bias (kg/m^2)	Absolute errors (mean ± SD) (kg/m^2)	95% LOA (kg/m^2)	RMSE
Aglago *et al.* [9], 2013	0.92	-1.02	1.16 ± 0.79	[-2.90 to 0.86]	1.4
Hofsteenge *et al.* [11], 2015	0.92	-0.47	0.63 ± 0.51	[-0.82 to 1.76]	0.82
Proposed	**0.98**	**-0.16**	**0.41 ± 0.24**	**[-1.04 to 0.72]**	**0.48**

Table 4:- Statistical Comparison of Proposed and Current Models (Female)

From the tables, it is seen that in every type of statistical analysis, the proposed models exhibit much better results than recent models. So, certainly the proposed models can be implemented in practical implementations.

V. CONCLUSIONS

As the proposed models for FFMI estimation possess excellent accuracy, these models can easily be implemented for the detection of different types of diseases with low cost and quickly. A large number of people cannot afford the diseases detection due to many problems. In future, these problems can be resolved by development of disease detection models from the proposed models.

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