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Original Research Article

A Population Specific Regression Model for Estimating Visceral Fat from BMI in Bengali Older Women

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Abstract

The older adult population of India is experiencing a rising prevalence of metabolic complications, with increased body fat, particularly visceral fat being a primary contributor. Early screening and detection of elevated visceral fat levels can facilitate timely lifestyle interventions and reduce the risk of metabolic disorders. The study aimed to develop and internally validate a population-specific linear regression model to estimate bioelectrical impedance-derived visceral fat from body mass index (BMI) among Bengali older women. This cross-sectional study included 217 Bengali older women aged 60-85 years, selected through simple random sampling from southern West Bengal. Standard anthropometric measurements were recorded, and visceral fat was estimated using bioelectrical impedance analysis (BIA). A simple linear regression model was developed using BMI as the predictor variable, with the sample split into training (70%) and testing (30%) subsets for internal validation. Bootstrapping with 1,000 resamples was applied to improve the robustness of parameter estimates. The regression model was statistically significant ($F = 2067.43$, $p < 0.001$) and explained 93% of the variance in BIA-derived visceral fat ($R^2 = 0.93$, adjusted $R^2 = 0.93$). The derived regression equation was: $VF = -16.889 + 1.065 \times BMI$. Regression diagnostics indicated that assumptions of linearity, homoscedasticity, and independence of residuals were adequately met. The internally validated model provides a cost-effective approach for estimating visceral fat at the population level among Bengali older women. The findings contribute to anthropological understanding of population-specific body composition in later life and may aid preliminary metabolic risk screening in resource-limited settings.

Keywords: Bengali older women, metabolic risk screening, visceral fat, linear regression model, ageing, biological anthropology.

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Introduction

India is undergoing a rapid demographic transition marked by a substantial rise in the older adult population. The population projection indicated that, the number of older adult population (aged 60 years and above) is expected to rise from 103 million in 2011 to nearly 230 million by 2036, representing a major shift in the country's age structure.[1] This demographic transformation is accompanied by an epidemiological transition which is characterized by a growing burden of malnutrition, non-communicable diseases, including diabetes mellitus, cardiovascular diseases, and hypertension, particularly among older populations.[2-5]

Ageing is associated with pronounced changes in body composition, including increases in total fat mass, redistribution of adipose tissue, and progressive declines in lean body mass.[6] Among different fat depots, visceral adipose tissue is of particular importance because of its metabolically active nature and its role in endocrine and inflammatory processes.[7-9] Accumulation of excess visceral fat (VF) has been consistently linked to insulin resistance, dyslipidaemia, and elevated cardiovascular risk, making it a critical marker of metabolic vulnerability in older adults.[10-12]

Patterns of fat distribution are not uniform across populations but are shaped by a complex interaction of genetic background, ethnicity, age, diet, physical activity, and socio-cultural practices.[13-15] South Asian populations, including Bengalis, are known to exhibit a tendency toward higher body fat and visceral adiposity at relatively lower levels of body mass index (BMI), a phenomenon often described as the "thin-fat" phenotype.[16-19] Among older women, these tendencies may be further accentuated by age-related hormonal changes, cumulative nutritional exposures, and gender-specific lifestyle constraints, particularly in low and middle income settings.[20,21]

Although imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI) provide accurate anatomical assessment of visceral adipose tissue, their high cost, technical complexity, and limited accessibility restrict their use in large-scale population studies and community-based research.[22] As a result, indirect methods such as bioelectrical impedance analysis (BIA) are frequently employed in anthropological and epidemiological investigations to estimate body fat compartments, including visceral fat, particularly in field settings.[23] It is important to note that BIA provides an indirect estimate of visceral adiposity based on impedance-derived algorithms rather than a direct imaging-based measurement of intra-abdominal fat, which should be considered when interpreting results.

Body mass index (BMI) remains one of the most widely used anthropometric indicators of nutritional status and general adiposity in population research due to its simplicity and feasibility.[24] While BMI does not directly measure body fat distribution, several studies have demonstrated a strong association between BMI and visceral fat indices across different age groups and populations.[25-27] However, population-specific variation necessitates locally derived models to improve interpretability and applicability.

Despite a growing body of research on ageing and metabolic health in India, there is a paucity of population-specific models examining the relationship between BMI and visceral fat among older women.[28] Therefore, the present study aims to develop and internally validate a simple linear regression model to estimate BIA-derived visceral fat using BMI among Bengali older women from southern West Bengal. By focusing on a specific ethnic and age group, the study seeks to contribute to the understanding of population-specific body composition patterns in later life and to provide a pragmatic tool for metabolic risk screening in resource limited settings.

Research Methodology

The study was carried out among 217 Bengali older women aged between 60 and 85 years from the seven southern districts of West Bengal i.e., Hooghly, Kolkata, North and South 24 Parganas, Howrah, Nadia, and Purba Bardhaman. A sampling frame was prepared using community household listings obtained from local administrative records and voter registration lists in the selected areas. From this compiled list of eligible older women, participants were selected through simple random sampling using a computer-generated random number sequence. Written informed

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consent was obtained from all participants prior to data collection. Body height (cm) and body weight (kg) were noted using anthropometric measurement set, and standardized weighing scale, following recommended procedures.[29] BMI was computed as body weight in kg, divided by the square of body height in meter. Visceral fat (VF) was estimated using a bioelectrical impedance analysis (BIA) analyzer (Omron HBF-375, KRELL PRECISION CO. LDT., China), which provides an indirect index of visceral adiposity.[30] All measurements were conducted in the morning hours to minimize diurnal variation. Participants were instructed to avoid heavy meals and vigorous physical activity for at least 8–10 hours prior to assessment and to empty their bladder before measurement. Measurements were taken in a standing posture with light clothing and without footwear. These standardized pre-assessment conditions were maintained to minimize hydration-related variability and improve reliability of impedance-based estimates.[31]

Ethical clearance was granted by the Institutional Human Ethical Committee of the University.

Inclusion criteria

Older women aged 60 years and above with self-reported confirmation on belonging to Bengali ethnicity and absences of chronic illness and medication that can affect hydration or body composition were included in the present study.

Exclusion criteria

Older women aged <60 years and not belonging to Bengali ethnicity, having neurodegenerative diseases, or having medications that can alter the body compositions were excluded from the present study.

Statistical analyses

The present study selected BMI as the primary predictor variable and VF as the outcome variable. BMI was chosen due to its widespread use as a simple, cost-effective, and easily obtainable anthropometric indicator in community-based and large-scale screening settings.[32] The objective of the study was to develop a feasible population-specific predictive model using a single, practical predictor variable. Although other anthropometric indicators such as waist circumference or age may also influence visceral fat distribution, the present model focused specifically on BMI to enhance applicability in resource-limited field settings.[33] To detect a meaningful relationship between the variables, power analysis was performed using G Power software to obtain the minimum requirement of samples for the equation.

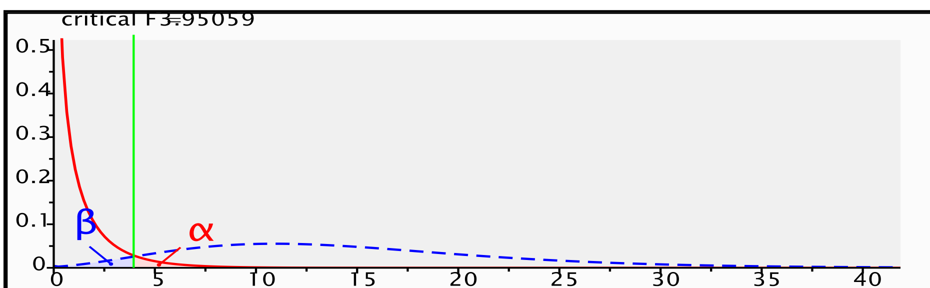

Fig. 1. Central and noncentral distribution of the population

G power estimated a minimum sample requirement of 89 for the present study.
Where, Effect size $f^2 = 0.15$ (Cohen's label: medium)
α error probability (significance level) = 0.05
Power (1-β) = 0.95
Predictors = 1
Noncentrality parameter (λ) = 13.35
Critical F = 3.9506
Actual power =0.951

Although 89 was the minimum requirement of sample, but to get more generalized and robust estimation, the study randomly selected 217 Bengali older women for the present study and categorized 152 (70% of all cases) older women as prediction set and 65 (30% of all cases) older women as validation set. Data analysis was performed using SPSS 31. After checking the outliers, descriptive statistics such as arithmetic mean and standard deviation along with t test and person's correlation were performed. Simple linear regression was performed between BMI and VF. To minimize the chance of violation of normality and homoscedasticity and obtain more robust estimates of standard error, bootstrap resampling (1000 iterations) was performed. Statistical significance was selected at $P < 0.05$.

Results

Table 1 presents the background profile of the study participants categorized as the prediction set and validation set.

Variables	Prediction set (n: 152)	Validation set (n: 65)	t	P value
Age (years)	67.8 ± 6.27	68.1 ± 7.48	0.30	0.76
Body height (cm)	148.4 ± 6.16	146.5 ± 6.27	2.07	0.04
Body weight (kg)	52.5 ± 11.27	50.1 ± 11.42	1.43	0.15
BMI ($kg.m^{-2}$)	23.7 ± 4.48	23.2 ± 4.50	0.75	0.45
VF (%)	8.4 ± 4.95	8.0 ± 4.62	0.56	0.58

Table 1. Background profile of the study participants

The bootstrapped (1000 times) linear regression equation developed was:

VF= -16.889 + 1.065 * BMI

The model was statistically significant ($F=2067.43$, $P<0.001$), and explained 93% of the variance in VF ($R^2=0.93$, adjusted $R^2= 0.93$). The high coefficient of determination indicates a strong linear association between BMI and BIA-derived visceral fat index in the studied population. It may also reflect partial construct overlap, as both BMI and BIA-derived visceral fat estimates are indicators of overall body composition, which could contribute to the strength of association. The co-linearity statistics VIF = 1 indicating no multi-co-linearity and Root Mean Square Error (RMSE) was 1.29 ensuring the good fit of the model.

The linear relationship between the BMI and VF has been presented through regression variable plot in Fig. 2.

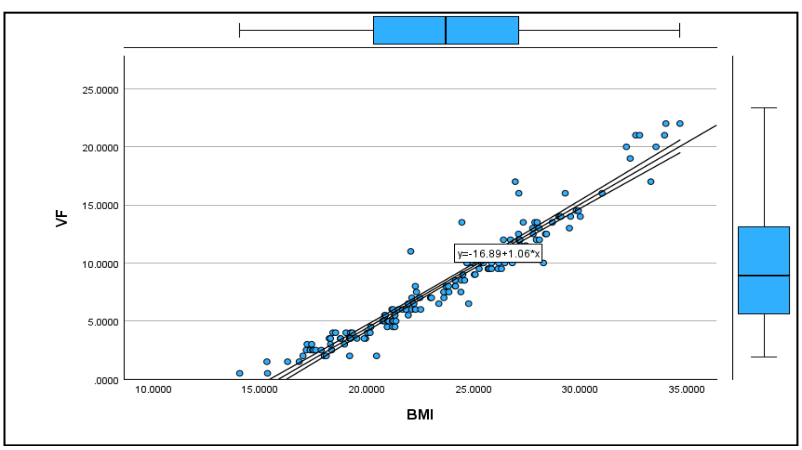

Fig. 2. Regression variable plot presenting the linear relationship between BMI and VF

Assumption testing Fig. 3 presents the standardized residuals against the standardized predicted values in scatter plot.

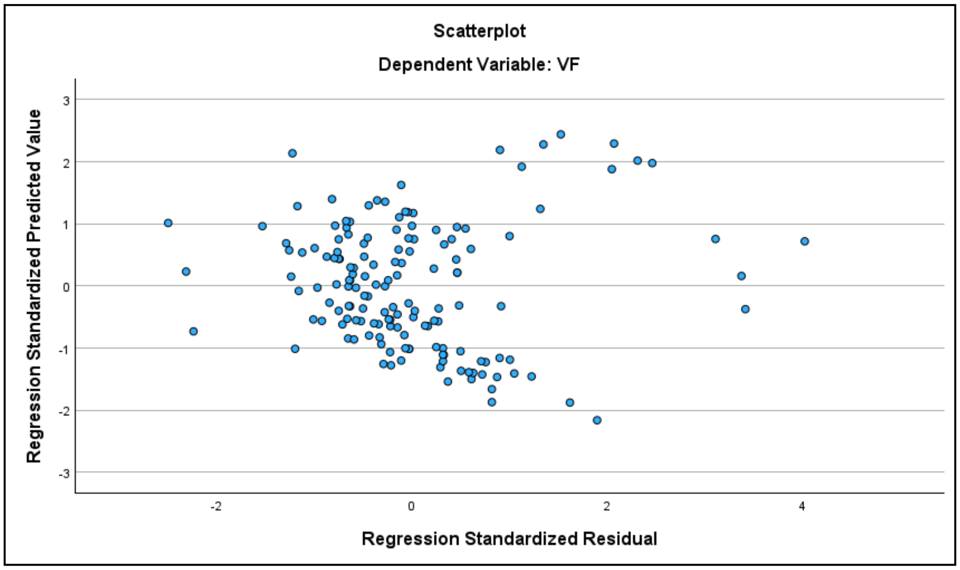

Fig. 3. Standardized residuals against the standardized predicted values

The scatter plot (Fig. 3) demonstrated a roughly random dispersion of points around the zero line, with no visible curvature. This suggests that the assumption of linearity was satisfied. The residuals appeared to be randomly and evenly distributed across all levels of predicted values, indicates the assumption of constant variance (homoscedasticity) was met. The Durbin-Watson statistic was 1.48, indicating independence of residuals. The internal validation of the model in terms of computed value from the equation and measured value (using BIA) of VF on the validation set has been presented in Table 2.

Computed value of VF (AM ± SD)	Measured value of VF (AM ± SD)	
7.8 ± 4.79	7.9 ± 4.62	t = 0.52 (P =0.61) r = 0.94 (P<0.001)

Table 2. The computed and measured value of VF on test set

The computed value of VF using the generated equation and measured value of VF using BIA showed no significant (P>0.05) differences and a strong correlation between them, suggesting high predictive consistency. Additionally, the mean absolute error (MAE) between computed and measured VF values was 3.81, indicating that, on average; the predicted values deviated from the measured values by 3.81 units. This magnitude of prediction error, when interpreted alongside the strong correlation and non-significant mean difference, suggests satisfactory predictive agreement for community-level estimation. Overall, the combined evidence from correlation analysis, absence of systematic bias, and mean absolute error supports the internal validity of the developed regression model.

Discussion

The present study examined the relationship between body mass index and bioelectrical impedance-derived visceral fat among Bengali older women and developed a population-specific regression model for estimating visceral fat from BMI. The findings demonstrate a strong positive association between BMI and visceral fat, with BMI explaining a substantial proportion of the variance in visceral fat estimates (R^2=0.93). This high explanatory power indicates

that, within this population, BMI serves as a strong statistical predictor of BIA-derived visceral adiposity. However, the strength of association may partly reflect shared underlying constructs, as both BMI and BIA-derived visceral fat index are influenced by overall body composition. Nonetheless, the results underscore the relevance of BMI as a practical anthropometric proxy for assessing central adiposity in older women at the population level.

The observed association reflects age-related changes in body composition, characterized by increased fat accumulation and altered fat distribution with advancing age. In women, particularly after menopause, hormonal changes contribute to a preferential deposition of fat in the abdominal and visceral regions, thereby increasing metabolic vulnerability.[34] The strong association observed in this study is consistent with earlier research conducted in Indian and other Asian populations, which has reported higher visceral adiposity at comparable or lower BMI values compared to Western populations.[35,36] Studies among older Asian cohorts have similarly reported moderate to strong associations between BMI and visceral fat indices, although the magnitude of explained variance varies across populations depending on ethnicity, age structure, and measurement method.[37-39] The relatively high R^2 observed in the present study may therefore reflect both ethnic specificity and methodological alignment between BMI and impedance-derived fat estimation.

The population specificity of the present findings is noteworthy. Bengali women are shaped by distinct dietary patterns, often characterized by carbohydrate-dense staples, as well as relatively low levels of structured physical activity in later life.[40-42] These factors, combined with socio-cultural constraints and cumulative life-course exposures, may contribute to greater visceral fat accumulation even within BMI ranges traditionally considered normal.[43,44] Such patterns highlight the importance of contextualizing anthropometric indicators within specific ecological, cultural, and biological frameworks.

“Beyond BMI Metrics” approach advocated by the Indian Council of Medical Research, reliance solely on BMI may underestimate cardiometabolic risk in Asian Indians.[45]

Emerging evidence suggests that waist

circumference and waist-hip ratio are superior indicators of visceral adiposity, particularly in the context of the “Thin Fat Indian” phenotype.[46,47] The undernutrition–recovery transitions observed in South-East Asia, especially India, incorporating central obesity measures may provide more accurate risk stratification.[48]

The regression model developed in this study demonstrated high internal predictive accuracy and minimal error when applied to an independent test subset. However, it is important to emphasize that the visceral fat values predicted by the model represent BIA-derived estimates rather than direct measurements obtained through imaging techniques such as CT or MRI. Furthermore, BIA measurements are sensitive to hydration status, recent physical activity, and device-specific algorithms, which may introduce variability in impedance-based estimates. Although standardized pre-measurement conditions were maintained in the present study, the model should therefore be interpreted as an estimation tool within similar field conditions rather than a substitute for direct anatomical assessment of visceral adipose tissue.

Despite these limitations, the model offers practical value for anthropological field studies and community-based research, where access to advanced diagnostic tools is limited. By providing a simple, non-invasive, and population-specific method for estimating visceral fat, the model may facilitate early identification of individuals at elevated metabolic risk and support comparative studies of ageing and body composition across populations.

The cross-sectional design of the study limits causal inference, and the findings are specific to Bengali older women, restricting generalizability to other ethnic or regional groups. External validation in independent cohorts of Bengali elderly women, as well as comparative evaluation in other South Asian populations, is warranted to establish broader applicability. Future research should seek external validation of the model in independent cohorts, incorporate biochemical markers of metabolic health, and explore non-linear or multivariate approaches that may better capture the complexity of body composition changes in ageing populations. Such efforts would further strengthen the understanding of fat distribution, metabolic risk, and ageing in diverse human populations.

Conclusion

This study demonstrates a strong population-specific association between BMI and BIA-derived visceral fat among Bengali older women, highlighting age and ethnicity related variation in body composition. The developed regression model predicts BIA-derived estimates of visceral adiposity rather than imaging-measured visceral adipose tissue, and therefore should be interpreted within the context of impedance-based assessment.

The proposed model offers a simple, non-invasive, and population-specific tool for anthropological and community-based research in settings with limited access to advanced body composition techniques. It may support preliminary community-level assessment of central adiposity; however, it is not intended to replace clinical diagnostic evaluation.

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Conflict of Interest

The authors declare no competing interest in carrying out, processing or publication of the present study.

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