Original Article

Bioelectrical impedance analysis predicts prehypertension and hypertension: A hospital-based cross-sectional study

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Abstract

Background: Hypertension prediction using anthropometry and bioimpedance offers practical advantages for screening. We aimed to analyze various anthropometric and bioelectrical impedance (BIA) estimates as predictive markers of prehypertension and hypertension. **Methods:** This cross-sectional analysis included 432 adult participants recruited from the medicine outpatient department of a tertiary hospital. Blood pressure measurements; anthropometric measurements of weight, body mass index, waist circumference, and hip circumference; and BIA (Omron HBF 375) were performed for body fat%, resting metabolic rate, visceral fat level, and skeletal muscle percentage. **Results:** Of the 432 participants comprising 220 males and 212 females, 36.8% were normotensive, 42% were prehypertensive, and 21% were hypertensive. Visceral fat (r 0.662, 95% CI: 0.60–0.72, $P < 0.001$) and resting metabolic rate (r 0.589, 95% CI: 0.52–0.65, $P < 0.001$) had the highest positive correlation, while skeletal muscle percentage (r -0.551, 95% CI: -0.62 to -0.48, $P < 0.001$) had a negative correlation with systolic blood pressure according to bivariate analysis. According to the receiver operating characteristic curve analysis for predicting hypertension, visceral fat volume had an area under curve (AUC) of 0.913, and resting metabolic rate had an AUC of 0.968, indicating the best predictive accuracy. **Conclusion:** Multiple BIA estimates, including high visceral fat content, resting metabolic rate, and adipose marker levels combined with low skeletal muscle percentage, were strongly associated with hypertension. Our analysis suggested the superiority of bioimpedance predictors over anthropometry-based prediction modeling alone for screening for hypertension in clinical practice.

Keywords: Bioelectrical impedance analysis, body composition, hypertension, prehypertension, skeletal muscle mass, visceral fat

Introduction

Hypertension was defined as a systolic blood pressure of at least 140 mmHg and/or a diastolic blood pressure of at least 90 mmHg. Hypertension is a substantial risk factor for the development of heart failure, stroke, peripheral vascular disease, and chronic kidney disorders.[1] According to estimates from the World Health Organization, hypertension affects 1.13 billion people worldwide, and blood pressure is under control in only 20% of those people, making it the leading cause of disease burden globally.[2,3] Hypertension is a multifactorial disease, and aging, a sedentary lifestyle, smoking, and high caloric diet intake are important risk factors.[4] Mechanistic studies have shown that oxidative stress, changes in circulating immune cell populations, dyslipidemia, imbalances in the serum electrolyte concentration, and genetics are key players in the development and progression of hypertension.[5-7] Thus, the management of

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hypertension involves a combination of medication and lifestyle changes. However, approximately one-third of persons living with hypertension fail to achieve proper blood pressure control even when three or more antihypertensive agents are prescribed.[8] This observation, coupled with the high mortality and morbidity associated with hypertension, suggests that all risk factors be defined and that their mechanism of action is elucidated.

Anthropometric indices, such as body mass index (BMI) and waist circumference, have been widely used as indicators of general and central obesity, respectively.[9,10] These indices are easily measurable and have been associated with an increased risk of hypertension. On the other hand, bioelectrical impedance analysis (BIA) measures, which assess body composition by analyzing the electrical properties of tissues, have also shown promise as potential predictors of hypertension.[11,12]

Additionally, a study conducted in Iran aimed to determine sex- and age-specific cutoff points for anthropometric indices to screen for hypertension.[13] Finally, a study in the Korean population analyzed the usefulness of anthropometric indices as predictors of hypertension.[14]

This study aimed to assess and compare the utility of anthropometric and bioelectrical impedance indices as potential predictors of hypertension in the West Gujarat population. By examining the associations between these indices and hypertension incidence, we aimed to identify effective predictors that can aid in the early detection and prevention of hypertension in this region.

Methodology

This was a hospital-based cross-sectional study involving all patients who visited the OPD clinics. The patients were from February 2023 to June 2023.

Sample size and sampling technique

Prevalence of hypertension in Gujarat = 20% (NFHS-5)[15] with 4% absolute error. Therefore, for a sample size of 384 and a 10% nonresponse rate, the total estimated sample size was 430. A total of 432 patients were included in the study by stratified random sampling. To ensure a diverse participant pool, the study employs stratified random sampling, categorizing individuals based on sex (male/female) and age group (18–30, 31–50, 51–65, >65 years). The strata proportions were determined based on the distribution of patients visiting the medicine outpatient department (OPD) over the course of 1 month. Participants were then randomly selected from each stratum in proportion to the stratum's representation in the OPD.

Inclusion and exclusion criteria

The inclusion criterion was age 18 years and older, irrespective of sex. The exclusion criteria for pregnant women were as follows: patients with chronic inflammatory conditions, patients receiving corticosteroid therapy, and individuals receiving pacemakers or implantable devices.

Data collection tools and techniques

A well-designed questionnaire was used to gather information from participants on their sociodemographic characteristics. Following established protocols, bioelectrical impedance, anthropometric impedance, and blood pressure measurements were taken. Using the necessary formulae, the anthropometric measurements were converted into derived measures of adiposity, including body mass index (BMI), body adiposity index (BAI), conicity index (CI), and abdominal volume index (AVI).

Blood pressure measurements and classification of the study participants

Before blood pressure readings, study participants were permitted to relax for at least 10 minutes, measured when the individuals were sitting; they were collected using a mercury sphygmomanometer. The estimated BP was calculated using the average of two readings. Hypertension was defined as diastolic levels greater than 140 mmHg and/or systolic values less than 90 mmHg. Systolic readings between 120 and 139 mmHg and/or diastolic readings between 80 and 89 mmHg were regarded as prehypertension, whereas readings below 120 mmHg and under 80 mmHg were regarded as normotensive.[1]

Anthropometric measurements and body composition parameters

Using a stadiometer, the respondents' height was measured without shoes and without leaning their heads up or down. The measurement was adjusted to the closest 0.1 cm. An Omron body composition analyzer (Omron Healthcare Co., Ltd.) was used to calculate the weight to the closest 0.1 kg. Although no wardrobe adjustments were performed, participants were advised to wear little clothing when their weight was determined. A body composition analyzer was subsequently used to calculate the visceral fat (VF), body fat percentage (BF), skeletal muscle mass (SM), and resting metabolic rate (RMR) according to age and sex. These samples were acquired according to the manufacturer's guidelines.

The derived measures of adiposity, such as the CI, AVI, and BAI, were calculated using the following formulas[16]:

Quality control measures

Rigorous quality control measures were implemented to ensure the accuracy and reliability of data collection. All personnel involved in anthropometric and BIA measurements underwent comprehensive training and standardization exercises before data collection commenced. Inter-rater reliability assessments were conducted periodically, and any discrepancies were promptly addressed through retraining and calibration of equipment. Furthermore, a random sample of 10% of the participants underwent repeat measurements by a separate team of trained personnel to assess inter-rater reliability, which was found to be satisfactory (intraclass correlation coefficients >0.90 for all measurements).

Statistical analysis

The collected data were subjected to rigorous statistical analysis using SPSS version 20. Descriptive analysis will provide an overview of the sample characteristics. ANOVA and *t*-tests were employed to explore differences among age and sex groups. Correlation and regression analyses were used to investigate the relationships between various health parameters. Additionally, receiver operating characteristic (ROC) curve analysis was conducted to assess the diagnostic performance of the selected variables, providing a nuanced understanding of their predictive capabilities. All *P* values are presented as two-tailed values, and *P* values < 0.05 were considered to indicate statistical significance.

The Ethical approval from the institutional ethical committee was taken before the start of the study (REF No-40/01/2023) dated on 07/01/2023.

Results

Table 1 shows the characteristics of the 432 participants divided into normotensive, prehypertensive, and hypertensive groups. The average age increased from 54 years in the normotensive group to 60 years in the hypertensive group (*P* = 0.002). The skeletal muscle mass percentage decreased from 32% in the normotensive group to 20% in the hypertensive group (*P* < 0.001), while the visceral fat, resting metabolic rate, and body fat percentage increased significantly from the normotensive to the hypertensive group (all *P* < 0.001). BMI and the CI did not differ between the groups, but the BAI and hip circumference were significantly greater in the hypertensive patients (*P* < 0.001 and *P* = 0.010, respectively).

Table 2 compares normotensive patients to patients in the combined prehypertensive and hypertensive groups. Similarly, the skeletal muscle percentage was significantly lower (30% vs 20%, *P* < 0.001), and the visceral fat, resting metabolic rate, and body fat percentage were significantly greater in the prehypertensive/hypertensive group than in the normotensive group (all *P* < 0.001). No significant differences were found between the groups for BMI, waist circumference, hip circumference, conicity index, AVI, or BAI.

Table 3 shows that systolic blood pressure was positively correlated with age (r = 0.132, 95% CI: 0.04-0.22, *P* = 0.006), waist circumference (r = 0.102, 95% CI: 0.01-0.19, *P* = 0.034), hip circumference (r = 0.104, 95% CI: 0.01-0.20, *P* = 0.03), BMI (r = 0.201, 95% CI: 0.11-0.29, *P* = 0.045), BMI (r = 0.100, 95% CI: 0.01-0.19, *P* = 0.037), BAI (r = 0.126, 95% CI: 0.03-0.22, *P* = 0.009), body fat percentage (r = 0.492, 95% CI: 0.41-0.57, *P* < 0.001), visceral fat (r = 0.662, 95% CI: 0.60-0.72, *P* < 0.001), and resting metabolic rate (r = 0.589, 95% CI: 0.52-0.65, *P* < 0.001). It correlated negatively with skeletal muscle percentage (r = -0.551, 95% CI: -0.62 to -0.48, *P* < 0.001).

Diastolic blood pressure correlated positively with age (r = 0.106, 95% CI: 0.01-0.20, *P* = 0.027), BMI (r = 0.156, 95% CI: 0.07-0.24, *P* = 0.02), BAI (r = 0.102, 95% CI: 0.01-0.19, *P* = 0.034), body fat percentage (r = 0.335, 95% CI: 0.25-0.42, *P* < 0.001), visceral fat (r = 0.460, 95% CI: 0.38-0.53, *P* < 0.001), and resting metabolic rate (r = 0.461, 95% CI: 0.38-0.53, *P* < 0.001). It correlated negatively with skeletal muscle percentage (r = -0.420, 95% CI: -0.50 to -0.34, *P* < 0.001).

Tables 4 and 5 show the ROC curve results for predicting prehypertension and hypertension, respectively. For predicting prehypertension, the skeletal muscle, visceral fat, resting metabolic rate, and body fat percentage had fair accuracy (AUC 0.730-0.848, *P* < 0.001). For predicting hypertension, skeletal

Table 1: Anthropometric and BIA characteristics of study participants in the normotensive, prehypertensive, and hypertensive groups

Variables	Normal (*n*=159)	Prehypertension (*n*=182)	Hypertension (*n*=91)	Total (*n*=432)	*P*
Age (in years)	54±15	55±13	60±12	58±11	0.002
Gender					
Male	69 (43)	101 (55%)	50 (55%)	220,51%	
Female	90 (57)	81 (45%)	41 (45%)	212,49%	
Weight (kg)	68.1±14.69	67.9±14.9	69±11.8	69±12	0.480
Bioimpedance Indices					
Skeletal muscle mass (SM) in %	32±9.0	22±6.4	20±4.7	26±5	<0.001**
Visceral fat level (VF)	10±7.6	18±6.7	22±10	20±9.2	<0.001**
Resting metabolic rate (RMR)	1196±174	1593±246	1784±305	1678±205	<0.001**
Body fat (BF) in %	22±6.7	25±8.4	30±8	28±8.3	<0.001**
Anthropometric Characteristics					
BMI (kg/m^2)	26±14	26±5	27±4.7	26.7±5	0.190
CI	1.39±0.15	1.40±0.15	1.42±0.1	1.41±0.1	0.031*
AVI	26.7±6.2	26.9±5.8	28.89±5.4	27.7±5.5	0.264
BAI	34.67±8	35±8.7	37.4±8.1	36.5±7	<0.001**
WC in cm	97.5±12	98±11	101.85±10	99±11	0.079
Hip circumference (HC) in cm	107±13.66	107.3±13	110±10.7	108±11	0.010*

P<0.05 significant, *P*<0.001 highly significant. Analyses were performed via ANOVA

Table 2: Comparison of anthropometric and BIA characteristics between normotensive and prehypertensive + hypertensive participants

Variables	Normal	Prehypertensive + Hypertensive	*P*
Weight (kg)	66.5±13.5	68.8±14.5	0.0565
Bioimpedance indices			
Skeletal muscle mass (SM) in %	20±6.7	30±9.0	<0.001**
Visceral fat level (VF)	15±10	24.10±7.6	<0.001**
Resting metabolic rate (RMR)	1096±174	1545±282	<0.001**
Body Fat (BF) in %	25.3±6.7	32.6±8.5	<0.001**
Anthropometric characteristics			
WC in m	97.5±12	98±10	0.109
Hip circumference (HC) in m	107±54	107±33	0.533
BMI in kg/m^2	26.8±25	27±25	0.920
CI	1.40±0.144	1.39±0.148	0.395
AVI	27.6±5.7	26.7±6.2	0.151
BAI	34±8.2	36±8.6	0.085

P<0.05-significant, *P*<0.001-highly significant. Analyses were performed via an unpaired *t*-test

Table 3: Correlation tables of the associations between different anthropometric indices and BIA indices and blood pressure

Variables	Systolic Blood Pressure, *r* (CI)	*P*	Diastolic Blood Pressure, *r* (CI)	*P*
Age	0.132 (0.04-0.22)	0.006**	0.106 (0.01-0.20)	0.027*
Weight	0.042 (-0.05-0.13)	0.379	0.008 (-0.09-0.10)	0.876
WC	0.102 (0.01-0.19)	0.034*	0.034 (-0.06-0.13)	0.481
HC	0.104 (0.01-0.20)	0.03*	0.054 (-0.04-0.15)	0.521
BMI	0.201 (0.11-0.29)	0.045*	0.156 (0.07-0.24)	0.02*
CI	0.04 (-0.05-0.13)	0.406	0.005 (-0.09-0.10)	0.910
AVI	0.100 (0.01-0.19)	0.037*	0.031 (-0.06-0.12)	0.521
BAI	0.126 (0.03-0.22)	0.009**	0.102 (0.01-0.19)	0.034*
BF	0.492 (0.41-0.57)	<0.001**	0.335 (0.25-0.42)	<0.001**
VF	0.662 (0.60-0.72)	<0.001**	0.460 (0.38-0.53)	<0.001**
RMR	0.589 (0.52-0.65)	<0.001**	0.461 (0.38-0.53)	<0.001**
SM%	-0.551 (-0.62--0.48)	<0.001**	-0.420 (-0.50--0.34)	<0.001**

P<0.05-significant, *P*<0.001-highly significant

muscle indices, visceral fat indices, resting metabolic rate, and body fat percentage again had good accuracy (AUC 0.851-0.968, *P* < 0.001).

In summary, increasing age, body fat, and visceral fat, along with decreasing skeletal muscle mass, were the factors most consistently associated with increased blood pressure or prehypertension/hypertension diagnosis. The resting metabolic rate also increases with increasing blood pressure. The body composition measurements of skeletal muscle, visceral fat, resting metabolic rate, and body fat percentage had good accuracy for discriminating between normotensive and hypertensive individuals.

Figure 1 BIA indices [Figure 1b] have better predictive accuracy (AUC = 0.854) than anthropometric indices alone for hypertension (Figure 1a, AUC = 0.785).

Table 4: ROC curve results for predicting prehypertension

Variable	Sensitivity	Specificity	Accuracy	AUC	*P*
Age	0.51	0.62	0.565	0.573	<0.001**
Weight	0.63	0.44	0.535	0.516	0.122
WC	0.471	0.501	0.486	0.492	0.415
HC	0.491	0.528	0.509	0.510	0.706
SM	0.612	0.752	0.682	0.730	<0.001**
VF	0.74	0.67	0.705	0.783	<0.001**
RMR	0.802	0.743	0.772	0.848	<0.001**
%BF	0.679	0.71	0.695	0.761	<0.001**
BMI	0.751	0.326	0.538	0.492	0.512
CI	0.526	0.456	0.491	0.483	0.673
AVI	0.421	0.532	0.476	0.469	0.274
BAI	0.485	0.565	0.525	0.543	0.152

P<0.05-significant, *P*<0.001-highly significant

Table 5: Results of ROC curves for predicting hypertension incidence

Variable	Sensitivity	Specificity	Accuracy	AUC	*P*
Age	0.48	0.57	0.544	0.544	<0.001**
Weight	0.71	0.329	0.571	0.510	0.621
WC	0.501	0.511	0.505	0.540	0.423
HC	0.491	0.478	0.486	0.498	0.541
SM	0.729	0.742	0.785	0.850	<0.001**
VF	0.84	0.87	0.854	0.913	<0.001**
RMR	0.912	0.883	0.894	0.968	<0.001**
%BF	0.769	0.81	0.785	0.851	<0.001**
BMI	0.961	0.126	0.653	0.542	0.231
CI	0.626	0.456	0.564	0.544	0.345
AVI	0.471	0.532	0.538	0.495	0.412
BAI	0.535	0.545	0.535	0.543	0.234

P<0.05-significant, *P*<0.001-highly significant

Discussion

The key findings of the current study indicate that BIA-derived indices such as high visceral fat content, resting metabolic rate, and body fat percentage, as well as low skeletal muscle percentage, are strongly associated with increased odds of prehypertension and hypertension.

The finding that greater visceral adiposity and body fat are important correlates of elevated blood pressure is consistent with earlier evidence.[17,18] Excess visceral fat and adiposity contribute to the dysregulation of adipocytokines, such as leptin, and increased insulin resistance—both mediators of hypertension development.[19]

The positive association of the resting metabolic rate in our data agrees with existing evidence on its linkages with increased cardiac output and blood pressure via sympathetic overactivity.[20,21] Its strong predictive accuracy reinforces its utility as a marker of hypertension risk.

The skeletal muscle percentage was significantly negatively correlated with blood pressure. This difference may be attributable to intermediate metabolites released by skeletal

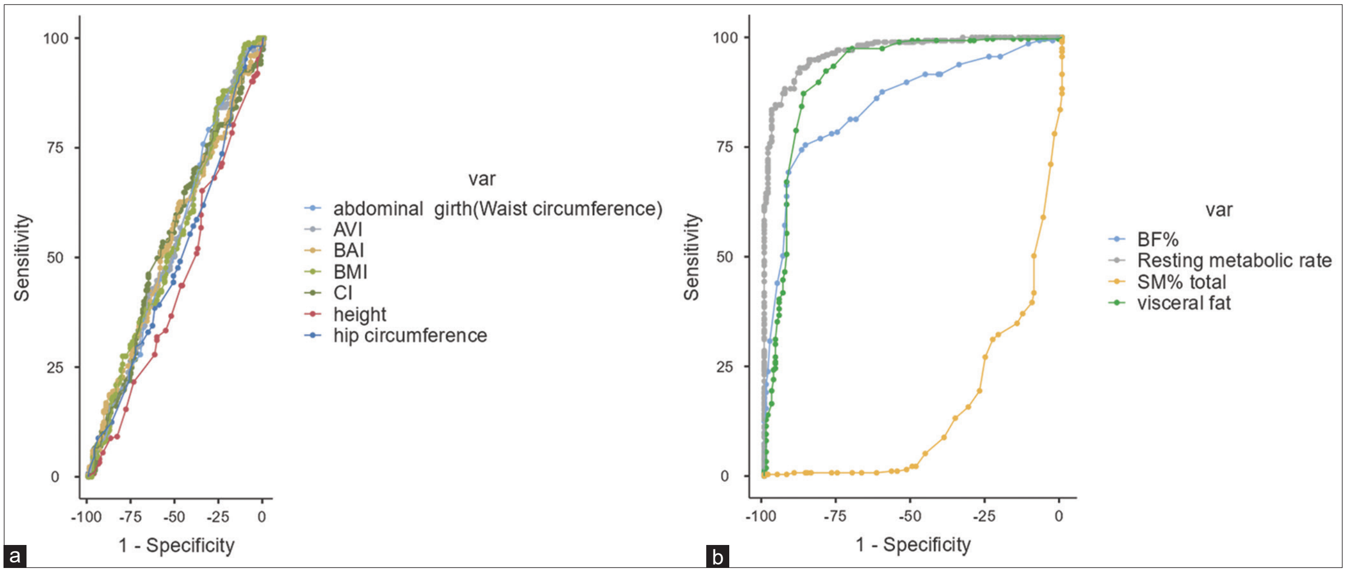

Figure 1: ROC curve of combined anthropometric (a) and BIA parameters (b)

muscle, which help in lowering vascular tone and peripheral resistance, as described previously.[22]

ROC analysis demonstrated that the skeletal muscle percentage (AUC 0.850), visceral fat (0.913), resting metabolic rate (0.968), and body fat percentage (0.851) had good accuracy for discriminating between normotensive and hypertensive individuals. These findings confirm results from earlier research relating altered body composition to hypertension.

Similarly, previous studies have also shown that reduced skeletal muscle has been hypothesized to contribute to hypertension development through insulin resistance, increased arterial stiffness, and overactivation of the sympathetic nervous system.[23]

Although the resting metabolic rate has not been widely investigated, our finding of an elevated RMR is consistent with the hyperdynamic circulation observed in hypertension patients. Previous research has also linked increased overall adiposity to hypertension,[24] reflected in our ROC curve analysis of body fat percentage.

Our ROC analysis corroborates earlier evidence identifying low muscle mass, excess visceral fat, heightened metabolism, and elevated adiposity as factors associated with hypertension development. Our AUCs confirm the usefulness of these particular body composition measures for discriminating between normotensive and hypertensive patients.

ROC analysis revealed that several body composition metrics had fair accuracy for predicting prehypertension, with skeletal muscle percentage (AUC 0.730), visceral fat (0.783), resting metabolic rate (0.848), and body fat percentage (0.761) having the best predictive ability.

Similarly, a study revealed that the skeletal muscle mass index was significantly lower in prehypertensive adults than in normotensive adults.[25] The area under the ROC curve (AUC) for skeletal muscle mass index (SMMI) in predicting prehypertension was 0.761 in their study, which was very similar to our value of 0.730. The visceral fat area has also been associated with prehypertension in previous work, with Ishizaka *et al*.[26] (2004) reporting an AUC of 0.731 for the visceral fat area predicting prehypertension. This finding aligns closely with our AUC of 0.783 for the visceral fat level.

The resting metabolic rate, a predictor of prehypertension, has not been extensively studied, but our findings of an elevated resting metabolic rate agree with the known increase in sympathetic nervous system activity that often precedes hypertension onset. Previous research has also shown that an increased body fat percentage is associated with a greater risk of prehypertension, which is again consistent with our ROC curve analysis.[27]

Overall, our ROC findings align with and strengthen the existing evidence linking diminished skeletal muscle mass, excess visceral adiposity, heightened resting metabolism, and increased overall adiposity to prehypertension development. Our study further established the potential predictive utility of these body composition parameters for identifying those at risk of progressing from normal blood pressure to prehypertension.

While BMI is a widely used anthropometric index, it has well-known limitations as a measure of adiposity as it does not differentiate between lean mass and fat mass. This limitation is particularly relevant in the context of our study as we observed that skeletal muscle mass and adiposity measures from BIA were more strongly associated with hypertension risk than BMI alone. Our findings underscore the importance of utilizing more comprehensive body composition assessments, such as BIA, to accurately evaluate hypertension risk, rather than relying solely on BMI.

In summary, this study provides valuable insights into the utility of BIA measures, especially visceral fat, resting metabolic rate, skeletal muscle mass, and body fat percentage, for predicting hypertension risk.

Limitations and recommendations

Limitations of our analysis include the cross-sectional design of our study as it does not allow for the assessment of temporal relationships or the establishment of causality between the observed associations. Prospective cohort studies are needed to evaluate the predictive value of BIA-derived indices over time and their potential for identifying individuals at risk of developing hypertension. Such longitudinal studies would provide a more robust understanding of the prognostic utility of these measures and inform the development of targeted preventive strategies. Additionally, the single-center nature of this study warrants additional confirmation in community settings. Nonetheless, as an initial hospital-based study, this study provides practical insights into utilizing adiposity measures from BIA to identify patients requiring aggressive lifestyle management and follow-up to curb the onset of adverse cardiovascular effects. It is important to acknowledge that our study did not account for potential confounding factors, such as dietary intake, physical activity levels, and socioeconomic status, which may influence both body composition and blood pressure. Future studies should aim to incorporate these variables to provide a more comprehensive understanding of the complex interplay between various factors and hypertension risk. Additionally, the cross-sectional nature of our study precludes the establishment of causality or the assessment of the predictive value of these measures over time. Prospective longitudinal studies are warranted to confirm the utility of BIA-derived indices in predicting the long-term risk of developing hypertension.

Based on our findings, we recommend that bioelectrical impedance devices be made available even at primary care facilities to enable routine visceral fat and muscle mass assessments and the calculation of predictive risk scores for hypertension.

Lifestyle measures targeting weight loss, reducing adiposity, and improving muscle strength need enhanced implementation at the population level for primordial prevention of hypertension.

Conclusion

In this hospital-based study of 432 adults, BIA revealed that high visceral fat content, elevated resting metabolic rate, and increased overall adiposity, as well as low skeletal muscle mass, were strongly associated with prehypertension and hypertension. The body composition parameters of visceral fat, resting metabolic rate, skeletal muscle percentage, and body fat percentage showed good predictive accuracy for discriminating between normotensive and hypertensive patients. These findings indicate that BIA can provide practical and accurate indicators of hypertension risk, particularly through measures of visceral fat, resting metabolic rate, skeletal muscle mass, and overall adiposity. Future research should explore the potential utility of BIA in community settings and primary care facilities for routine screening and risk stratification. Prospective cohort studies are recommended to establish the long-term predictive value of these measures and inform the development of targeted preventive strategies for hypertension management.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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