BMC Pediatrics

RESEARCH

Open Access

Association of body composition with ambulatory blood pressure among Chinese youths

Bin Mao[1], Jixin Zhang[1], Shengnan Li[1], Zehui Fan[1], Ying Deng[1], Hongjiao Quan[1] and Yide Yang[1*]

Abstract

Background For youths, abnormalities in ambulatory blood pressure (ABP) patterns are known to be associated with increased cardiovascular disease risk and potential target organ damage. Body composition, including indicators such as lean mass index (LMI), fat mass index (FMI), and visceral fat level (VFL), plays a significant role in blood pressure (BP) regulation. However, little is known about the association between these body composition indicators and ABP. Therefore, the present study examined the association between these body composition indicators and BP among Chinese youths.

Methods A total of 477 college students aged 17 to 28 years old (mean ± Standard deviation = 18.96 ± 1.21) from a university in Changsha, Hunan Province, China, were included in this study. Body composition indicators were measured with a bioelectrical impedance body composition analyzer, and 24-hour ambulatory blood pressure monitoring (ABPM) was conducted. Multivariable logistic regression was performed to assess the relationship between body composition indicators and abnormal ABP.

Results The prevalence of abnormal BP, including 24-hour BP, daytime BP, nighttime BP, and clinic BP, were 4.8%, 4.2%, 8.6%, and 10.9%, respectively. After adjusting for potential covariates, LMI [abnormal 24-hour BP (OR = 1.85, 95%CI:1.31, 2.62), abnormal daytime BP (OR = 1.76, 95%CI:1.21, 2.58), abnormal nighttime BP (OR = 1.64, 95%CI:1.25, 2.14), abnormal clinic BP (OR = 1.84, 95%CI:1.38, 2.45)], FMI [abnormal 24-hour BP (OR = 1.20, 95%CI:1.02, 1.41), abnormal daytime BP (OR = 1.30, 95%CI:1.07, 1.57), abnormal nighttime BP (OR = 1.24, 95%CI:1.10, 1.39), abnormal clinic BP (OR = 1.42, 95%CI:1.22, 1.65)], and VFL [abnormal 24-hour BP (OR = 1.22, 95%CI:1.06, 1.39), abnormal daytime BP (OR = 1.29, 95%CI:1.10, 1.51), abnormal nighttime BP (OR = 1.24, 95%CI:1.12, 1.39), abnormal clinic BP (OR = 1.38, 95%CI:1.21, 1.57)] are positively linked to abnormal BP. Additionally, there were significant sex differences in the association between body composition and abnormal BP.

Conclusions Our findings suggested maintaining an individual's appropriate muscle mass and fat mass and focusing on the different relations of males' and females' body composition is crucial for the achievement of appropriate BP profiles.

Keywords Lean mass index, Fat mass index, Visceral fat level, Ambulatory blood pressure, Chinese youths

*Correspondence:
Yide Yang
yangyide2007@126.com
[1]Key Laboratory of Molecular Epidemiology of Hunan Province, School of Medicine, Hunan Normal University, Changsha 410081, China

Introduction

In recent years, cardiovascular disease has become the leading cause of global social burden and economic burden [1]. Hypertension is the leading contributor to cardiovascular diseases such as heart attacks and strokes, and its prevalence is progressively escalating [2]. From 1999 to 2019, there has been a significant increase in the prevalence of hypertension among adults aged 30–79 globally, both in men and women. Specifically, the number of individuals in this age group with hypertension has nearly doubled over the course of two decades [3]. Additionally, the prevalence of hypertension among Chinese adults reached 44.7% in 2017 according to a China PEACE Million Persons Project [4]. Furthermore, it is worth mentioning that the prevalence of hypertension was 22.1% among young Chinese by 2022 [5].

Excessive energy intake [6] and sedentary lifestyle [7], alongside individual weight gain and obesity, have been identified as significant factors contributing to the hypertension epidemic. A meta-analysis including 57 cohort studies has demonstrated that an escalating body mass index (BMI) is associated with elevated blood pressure (BP) and hypertension [8]. BMI is widely used as a general indicator to evaluate overall obesity; however, it could not accurately capture the specific distribution of muscle and fat throughout the body as adequately as lean mass index (LMI), fat mass index (FMI) and visceral fat levels (VFL). It has been demonstrated that there is a positive correlation between increased lean mass and hypertension [9]. Likewise, an elevated fat mass has been linked to higher odds ratios for developing hypertension [10]. Moreover, it has been discovered that increased VFL, reflecting the proportion of visceral fat, is connected to higher mean BP levels [11]. Until now, the relationship between 24-hour ambulatory BP (ABP) and body composition parameters has not been thoroughly studied. Previous studies investigating the relationship between body composition and BP levels have predominantly relied on clinic BP measurements, which do not reflect nighttime BP and BP's circadian rhythmicity [12–14]. However, nighttime BP was a better predictor of cardiovascular death than clinic BP [15]. Twenty-four-hour ambulatory blood pressure monitoring (ABPM) is a widely recognized gold standard for the comprehensive assessment and diagnosis of hypertension. Unlike clinic BP measurements, ABPM offers a more detailed and accurate evaluation of BP patterns (including daytime BP, nighttime BP, and BP circadian rhythmicity) throughout the entire 24-hour period [16, 17]. Meanwhile, previous studies on the association between body composition and ABP were conducted in the USA [18]and Turkey [19], whereas the study in China was based on old adults [20]. Research on the youth population in China is currently insufficient. Therefore, we aim to assess the relationship between body composition (LMI, FMI, and VFL) and BP indicators obtained by 24-hour ABPM among Chinese college students after controlling for potential confounders. Meanwhile, since significant sex differences existed in both BP and obesity indicators [21, 22], we also explored how the relationship between body composition and ABP differed between males and females.

Methods

Study participants

A total of 600 college students were recruited between June 2022 and June 2023 in Changsha, Hunan province, China. The inclusion criteria for the study participants were as follows: (a)college students who voluntarily expressed interest in participating in this study, (b) college students who were able to complete questionnaires, physical examinations, and clinic and ABP measurements, and (c)college students without acute illness such as fever. Among the 600 participants involved in this study, a total of 477 individuals (124 males and 353 females) aged 17 to 28 years old (mean ± Standard deviation = 18.96 ± 1.21) remained for this final analysis after 123 participants were excluded because of the absence of basic demographic data (n=59), body composition (n=50), clinic BP data (n=3), and complete ABPM data (n=11). Among the 477 participants included in this study, 96.6% were under the age of 22. All participants provided informed consent before the initiation of the study. The current study was approved by the Medical Research Ethical Review Committee Board of Hunan Normal University (2019-88).

Measurements

General information

Height was measured with a stadiometer to the closest 0.1 cm with no shoes; weight was measured with a bioelectrical impedance body composition analyzer (Model TANITA MC-780MA, Japan) to the closest 0.1 kg without wearing heavy clothing and shoes. Waist circumference (WC) was measured at 1 cm above the umbilicus with a tape to the closest 0.1 cm. Body mass index is calculated as weight (kg)/ height squared (m^2). The information, including participants of sociodemographic factors, lifestyle factors, and parental history of hypertension, was obtained by a self-administered questionnaire with proper instruction. The sociodemographic factors were composed of sex, age (years), nationality (Han nationality and other), and family per capita monthly income (CNY) (<3000, 3000–4999, ≥5000, and unclear). The lifestyle factors were comprised of salt intake habits, smoking, drinking, frequency of fruit intake (<1 time/day and ≥1 time/day), frequency of vegetable intake (<1 time/day and ≥1 time/day) and moderate-vigorous physical activity (MVPA) (<1 h/day and ≥1 h/day). The frequency of fruit and vegetable intake was measured by the following question: How many times have you eaten fruit or vegetables in the past week?

BP measurements and body composition examinations

For clinic BP, a mercury sphygmomanometer (Yutu XJ11D, Shanghai, China) or electronic sphygmomanometer (Type: OMRON, HBP-1320) was used with cuffs of suitable size applied to the right arm after 5 min of rest in the sitting position. The average of three measurements was recorded as clinic BP. Abnormal clinic BP was defined as systolic BP (SBP)≥140 mmHg or diastolic BP (DBP)≥90 mmHg [23].

The ABP of participants was measured using the TM-2430 blood pressure monitor (A&D, Japan), which was applied to the non-dominant arm. The measurement protocol included recording every 20 min during the daytime (from 7:00 AM to 11:00 PM) and the nighttime (from 11:00 PM to 7:00 AM) recording every 30 min. All participants successfully completed a full 24-hour ABPM session, as specified by the European Society of Hypertension, with at least 70% of the planned readings, including a minimum of 20 daytime readings and 7 nighttime readings [24]. Abnormal 24-hour BP was defined as SBP≥130 mmHg and/or DBP≥80 mmHg. Abnormal daytime BP was defined as SBP≥135 mmHg and/or DBP≥85 mmHg. In addition, abnormal nighttime BP was defined as SBP≥120 mmHg and/or diastolic BP≥70 mmHg [25, 26].

The body composition of participants, including total body fat, lean mass, and VFL, were obtained with a TANITA body composition analyzer (MC 780MA). When measuring the body composition, with metal objects removed, participants stood barefoot on the instrument and held the handle with both hands while waiting to complete the test. Body composition parameters, including LMI (calculated as lean body mass divided by the square of height), FMI (calculated as fat mass divided by the square of height), and VFL, were included in the final analysis.

Statistical analysis

Categorical and continuous variables were described as number (proportion) and mean (Standard deviation, SD), respectively. The sex difference was tested using the Chi-square ($\chi2$) test for categorical variables and the Wilcoxon rank sum test and/or two independent samples t-test for continuous variables. Spearman correlation analyses were conducted to examine the correlation between body composition indicators and all ABPM components, as well as clinic BP (both SBP and DBP). Binary logistic regression models were fitted to analyze the relationship between LMI, FMI, and VFL with abnormal daytime/nighttime/24-hour BP and abnormal clinic BP. In model 1, we only adjusted age. For model 2, we further adjusted nationality, family per capita monthly income, salt intake habits, smoking, drinking, parental history of hypertension, frequency of fruit intake, frequency of vegetable intake, and MVPA. All models were adjusted for sex in total population analyses. The odds ratio (OR) and 95% confidence intervals (CIs) were used as the estimates of parameters in the models. All analyses were conducted using the R (version 4.2.2) and IBM SPSS (version 25.0). Two-sides test was used for all tests, and $P<0.05$ was considered statistically significant.

Results

The characteristics of the study population are shown in Table 1. A total of 477 college students (74.0% females) were included in the final analysis. The mean WC, BMI, LMI, and VFL were higher in males than females, while females' FMI was significantly higher than males ($P<0.001$). The prevalence of abnormal BP, including 24-hour BP, daytime BP, nighttime BP, and clinic BP, were 4.8%, 4.2%, 8.6%, and 10.9%, respectively. Males had a higher prevalence of abnormal BP across all categories than females ($P<0.05$). Additionally, males had a higher 24-hour BP, daytime BP, nighttime BP, and clinic BP (both SBP and DBP) than females ($P<0.05$). There were significant differences in age, nationality, drinking, and MVPA of different sex groups.

Table 2 illustrates the correlates of body composition indicators and all 24-hour AMBP components, and clinic BP (both SBP and DBP). WC, BMI, LMI, and VFL were correlated to 24-hour BP, daytime BP, nighttime BP, and clinic BP (both SBP and DBP), with correlation coefficients ranging from 0.12 to 0.57. FMI was correlated to 24-hour DBP and clinic DBP with correlation coefficients of 0.09 and 0.13 but was not associated with 24-hour/daytime/nighttime/clinic SBP.

The relationship between body composition indicators and abnormal BP (24-hour, daytime, nighttime, and clinic) was presented in Table 3. After adjustment of sex and age, LMI [abnormal 24-hour BP (OR=1.87, 95%CI:1.39, 2.53), abnormal daytime BP (OR=1.71, 95%CI:1.26, 2,31), abnormal nighttime BP (OR=1.58, 95%CI:1.25, 2.01), abnormal clinic BP (OR=1.73, 95%CI:1.36, 2.20)], FMI [abnormal 24-hour BP (OR=1.25, 95%CI:1.08, 1.44), abnormal daytime BP (OR=1.29, 95%CI:1.11, 1.51), abnormal nighttime BP (OR=1.23, 95%CI:1.10, 1.38), abnormal clinic BP (OR=1.39, 95%CI:1.21, 1.59)], and VFL [abnormal 24-hour BP (OR=1.24, 95%CI:1.10, 1.39), abnormal daytime BP (OR=1.25, 95%CI:1.11, 1.41), abnormal nighttime BP (OR=1.23, 95%CI:1.12, 1.36), abnormal clinic BP (OR=1.33, 95%CI:1.19, 1.49)] are positively linked to

Table 1 Characteristics of the study population

Variables Mean (SD)/*n* (%)	Total (*n* = 477)	Males (*n* = 124)	Females (*n* = 353)	*P* value
Age (years)	18.96 (1.21)	18.77 (1.07)	19.04 (1.25)	**0.026**
Nationality				
Han nationality	429 (89.9)	105 (84.7)	324 (91.8)	**0.024**
Other	48 (10.1)	19 (15.3)	29 (8.2)	
Family per capita monthly income (yuan)				
< 3000	76 (15.9)	14 (11.3)	62 (17.6)	0.114
3000–4999	125 (26.2)	27 (21.8)	98 (27.7)	
≥5000	139 (29.1)	41 (33.0)	98 (27.8)	
Unclear	137 (28.8)	42 (33.9)	95 (26.9)	
Salt intake habit				
High intake of salt	92 (19.3)	23 (18.5)	69 (19.5)	0.344
Moderate intake of salt	319 (66.9)	88 (71.0)	231 (65.5)	
Low intake of salt	58 (12.1)	10 (8.1)	48 (13.6)	
Unclear	8 (1.7)	3 (2.4)	5 (1.4)	
Smoking				
Yes	4 (0.8)	2 (1.6)	2 (0.6)	0.272
No	473 (99.2)	122 (98.4)	352 (99.4)	
Drinking				
Yes	34 (7.1)	21 (16.9)	13 (3.7)	**< 0.001**
No	443 (92.9)	103 (83.1)	340 (96.3)	
Parental history of hypertension				
Either parent	99 (20.8)	20 (16.1)	79 (22.4)	0.140
Neither parent or unclear	378 (79.2)	104 (83.9)	274 (77.6)	
Frequency of fruit intake				
< 1time/day	391 (82.0)	106 (85.5)	285 (80.7)	0.237
≥ 1time/day	86 (18.0)	18 (14.5)	68 (19.3)	
Frequency of vegetable intake				
< 1time/day	175 (36.7)	40 (32.3)	135 (38.2)	0.234
≥ 1time/day	302 (63.3)	84 (67.7)	218 (61.8)	
MVPA				
< 1 h/day	460 (96.0)	114 (91.9)	346 (98.0)	**0.002**
≥ 1 h/day	17 (4.0)	10 (8.1)	7 (2.0)	
WC, cm	70.30 (7.88)	76.31 (8.89)	68.19 (6.25)	**< 0.001**
BMI, kg/m^2	21.27 (3.32)	22.26 (3.95)	20.92 (2.99)	**0.001**
Body composition indices				
LMI, kg/m^2	15.82 (1.97)	18.35 (1.79)	14.93 (1.03)	**< 0.001**
FMI, kg/m^2	5.45 (2.46)	3.92 (2.53)	5.99 (2.20)	**< 0.001**
VFL	2.96 (2.77)	4.81 (3.83)	2.31 (1.92)	**< 0.001**
Office BP mmHg				
Normal	425 (89.1)	79 (63.7)	346 (98.0)	**< 0.001**
Abnormal	52 (10.9)	45 (36.3)	7 (2.0)	
SBP	120 (14)	134 (13)	116 (11)	**< 0.001**
DBP	74 (15)	77 (18)	73 (13)	**< 0.001**
24 h BP				
Normal	454 (95.2)	106 (85.5)	348 (98.6)	**< 0.001**
Abnormal	23 (4.8)	18 (14.5)	5 (1.4)	
SBP	108 (11)	117 (10)	104 (8)	**< 0.001**
DBP	66 (5)	68 (5)	66 (5)	**< 0.001**
Day-time BP				
Normal	457 (95.8)	107 (86.3)	350 (99.2)	**< 0.001**
Abnormal	20 (4.2)	17 (13.7)	3 (0.8)	
SBP	111 (12)	122 (11)	107 (9)	**< 0.001**

Table 1 (continued)

Variables Mean (SD)/*n* (%)	Total (*n* = 477)	Males (*n* = 124)	Females (*n* = 353)	*P* value
DBP	69 (6)	72 (6)	68 (5)	**< 0.001**
Night-time BP				
Normal	436 (91.4)	107 (86.3)	329 (93.2)	**0.018**
Abnormal	41 (8.6)	17 (13.7)	24 (6.8)	
SBP	100 (10)	106 (11)	98 (9)	**< 0.001**
DBP	60 (6)	61 (6)	60 (6)	0.069

Abbreviations WC, Waist circumference; BMI, body mass index; LMI, lean mass index; FMI, fat mass index; VFL, visceral fat level; SBP, systolic blood pressure; DBP, diastolic blood pressure; MVPA, moderate-vigorous physical activity

Wilcoxon rank sum test and/or two independent samples t-test for r continuous variables and χ2 test for categorical variables. *P* value < 0.05 are set in bold

Table 2 Correlation matrix of selected variables (duplicates omitted)

	WC	BMI	LMI	FMI	VFL
WC	-	-	-	-	-
BMI	0.79***	-	-	-	-
LMI	0.74***	0.69***	-	-	-
FMI	0.41***	0.73***	0.08	-	-
VFL	0.80***	0.86***	0.63***	0.55***	-
24-hour SBP	0.49***	0.36***	0.55***	0.01	0.43***
24-hour DBP	0.31***	0.25***	0.28***	0.09*	0.29***
Daytime SBP	0.49***	0.36***	0.54***	0.01	0.43***
Daytime DBP	0.33***	0.25***	0.30***	0.08	0.31***
Nighttime SBP	0.35***	0.25***	0.36***	0.04	0.27***
Nighttime DBP	0.18***	0.14***	0.15**	0.08	0.12**
Clinic SBP	0.52***	0.41***	0.57***	0.04	0.48***
Clinic DBP	0.29***	0.25***	0.26***	0.13*	0.32***

*, $P<0.05$; **, $P<0.01$; ***, $P<0.001$. WC, Waist circumference; BMI, body mass index; LMI, lean mass index; FMI, fat mass index; VFL, visceral fat level; SBP, systolic blood pressure; DBP, diastolic blood pressure; MVPA, moderate-vigorous physical activity

ABP. Even after adjustment for the potential covariates, the associations remained significant.

Meanwhile, sex differences exist in the association between body composition indicators and ABPM components. In males, all body composition indicators exhibit a statistically significant association with abnormal ambulatory BP ($P<0.05$). However, in females, only LMI and VFL are significantly related to abnormal night-time BP ($P<0.05$).

Discussion

To the best of our knowledge, this is the first study of the association between body composition and ABP indicators conducted among relatively healthy young adults. We found that LMI, FMI, and VFL were positively associated with abnormal BP among college students, both based on 24-hour ABPM and clinic BP. This association was consistent after adjusting for potential confounding factors, but there is a significant sex difference in the association between body composition indicators and abnormal BP phenotypes obtained from 24-hour ABPM. Specifically, for 24 h ABPM indicators, all body composition indicators are significantly associated with abnormal ABP in males (mean ± SD = 18.77 ± 1.07). However, in females (mean ± SD = 19.04 ± 1.25), only LMI and VFL are significantly related with abnormal night-time BP.

The prevalence of abnormal 24-hour BP in Asian adults within a hospital-based study (mean age 57 years) was reported as 56.4% [27], which is strikingly higher than the 4.8% observed in this study (mean ± SD = 18.96 ± 1.21). The discrepancy may be due to age and specific study populations [28, 29]. Furthermore, this study found that there are sex differences in the prevalence of abnormal 24-hour BP (14.5% in males and 1.4% in females). Such differences may be attributed to hormones and levels of visceral fat in the body. Estrogen can indirectly regulate BP by reducing the calcium pathway and indirectly through genomic action [30], whereas androgens may increase BP by activating the renin-angiotensin-aldosterone system [31]. Moreover, previous study has shown that a high VFL is associated with the risk of hypertension [32]. In our study, males had significantly higher VFL than females.

Although previous studies have explored the relationship between lean mass and BP, these results have been inconsistent. A study involving 211 participants found no significant association between lean mass percentage and elevated BP or hypertension [33]. However, another study among 50,159 participants in America has revealed that lean mass exhibited a significant positive correlation with hypertension in the comprehensive adjustment model [34]. Additionally, Korhonen et al. discovered that LMI has a positive relationship with 24-hour BP components [35]. Our findings indicate that increased LMI not only escalates the risk of abnormal clinic BP but also elevates the risk of abnormal ABP. This relationship may result from several mechanisms. First, the increase in lean mass contributes to enhanced vascular compliance, resulting in the activation of the renin-angiotensin-aldosterone system (RAAS), consequently influencing hypertension [36, 37]. Second, high lean mass can lead to excessive activation of the sympathetic nervous system, resulting in vasoconstriction and elevated BP [34]. Finally,

Table 3 Multinomial logistic regression models evaluating the associations of body composition indicators with risk of abnormal BP based on 24 h ABPM and clinic BP

	Abnormal 24 h BP			Abnormal day-time BP			Abnormal night-time BP			Abnormal clinic BP		
	Normal	OR (95% CI)	*P*	Normal	OR (95% CI)	*P*	Normal	OR (95% CI)	*P*	Normal	OR (95% CI)	*P*
Total												
Model 1												
LMI	Ref.	1.87 (1.39, 2.53)	**< 0.001**	Ref.	1.71 (1.26, 2.31)	**0.001**	Ref.	1.58 (1.25, 2.01)	**< 0.001**	Ref.	1.73 (1.36, 2.20)	**< 0.001**
FMI	Ref.	1.25 (1.08, 1.44)	**0.003**	Ref.	1.29 (1.11, 1.51)	**0.001**	Ref.	1.23 (1.10, 1.38)	**< 0.001**	Ref.	1.39 (1.21, 1.59)	**< 0.001**
VFL	Ref.	1.24 (1.10, 1.39)	**< 0.001**	Ref.	1.25 (1.11, 1.41)	**< 0.001**	Ref.	1.23 (1.12, 1.36)	**< 0.001**	Ref.	1.33 (1.19, 1.49)	**< 0.001**
Model 2												
LMI	Ref.	1.85 (1.31, 2.62)	**0.001**	Ref.	1.76 (1.21, 2.58)	**0.003**	Ref.	1.64 (1.25, 2.14)	**< 0.001**	Ref.	1.84 (1.38, 2.45)	**< 0.001**
FMI	Ref.	1.20 (1.02, 1.41)	**0.030**	Ref.	1.30 (1.07, 1.57)	**0.007**	Ref.	1.24 (1.10, 1.39)	**0.001**	Ref.	1.42 (1.22, 1.65)	**< 0.001**
VFL	Ref.	1.22 (1.06, 1.39)	**0.005**	Ref.	1.29 (1.10, 1.51)	**0.002**	Ref.	1.24 (1.12, 1.39)	**< 0.001**	Ref.	1.38 (1.21, 1.57)	**< 0.001**
Males												
Model 1												
LMI	Ref.	1.80 (1.30, 2.49)	**< 0.001**	Ref.	1.78 (1.28, 2.46)	**0.001**	Ref.	1.46 (1.08, 1.98)	**0.015**	Ref.	1.54 (1.21, 1.96)	**< 0.001**
FMI	Ref.	1.39 (1.15, 1.68)	**0.001**	Ref.	1.38 (1.14, 1.67)	**0.001**	Ref.	1.38 (1.14, 1.67)	**0.001**	Ref.	1.38 (1.15, 1.64)	**< 0.001**
VFL	Ref.	1.29 (1.13, 1.48)	**< 0.001**	Ref.	1.28 (1.12, 1.47)	**< 0.001**	Ref.	1.23 (1.07, 1.40)	**0.003**	Ref.	1.28 (1.14, 1.45)	**< 0.001**
Model 2												
LMI	Ref.	1.87 (1.23, 2.85)	**0.003**	Ref.	1.97 (1.27, 3.06)	**0.002**	Ref.	1.68 (1.03, 2.75)	**0.036**	Ref.	1.68 (1.24, 2.29)	**0.001**
FMI	Ref.	1.35 (1.07, 1.71)	**0.013**	Ref.	1.37 (1.08, 1.75)	**0.010**	Ref.	1.53 (1.07, 2.19)	**0.021**	Ref.	1.48 (1.17, 1.88)	**0.001**
VFL	Ref.	1.31 (1.09, 1.57)	**0.004**	Ref.	1.34 (1.11, 1.63)	**0.003**	Ref.	1.31 (1.03, 1.67)	**0.029**	Ref.	1.39 (1.18, 1.63)	**< 0.001**
Females												
Model 1												
LMI	Ref.	2.24 (1.11, 4.53)	**0.025**	Ref.	1.17 (0.43, 3.22)	0.757	Ref.	1.81 (1.25, 2.63)	**0.002**	Ref.	3.16 (1.68, 5.92)	**< 0.001**
FMI	Ref.	0.75 (0.42, 1.33)	0.319	Ref.	0.90 (0.51, 1.61)	0.732	Ref.	1.14 (0.98, 1.33)	0.100	Ref.	1.39 (1.13, 1.72)	**0.002**
VFL	Ref.	0.82 (0.42, 1.59)	0.551	Ref.	0.75 (0.29, 1.94)	0.548	Ref.	1.25 (1.07, 1.46)	**0.005**	Ref.	1.48 (1.20, 1.83)	**< 0.001**
Model 2												
LMI	Ref.	2.00 (0.79, 5.07)	0.143	Ref.	1.01 (0.29, 3,51)	0.984	Ref.	1.81 (1.21, 2.72)	**0.004**	Ref.	4.32 (1.75, 10.64)	**0.001**
FMI	Ref.	0.71 (0.40, 1.26)	0.245	Ref.	0.95 (0.50, 1.83)	0.886	Ref.	1.12 (0.94, 1.32)	0.198	Ref.	1.39 (1.10, 1.77)	**0.007**
VFL	Ref.	0.76 (0.42, 1.36)	0.349	Ref.	0.63 (0.25, 1.56)	0.313	Ref.	1.24 (1.04, 1.47)	**0.016**	Ref.	1.52 (1.17, 1.97)	**0.002**

Model 1: Adjusted for age

Model 2: Adjusted for age, nationality, family per capita monthly income, salt intake habit, smoking, drinking, parental history of hypertension, frequency of fruit intake, frequency of vegetable intake, and MVPA. LMI, lean mass index; FMI, fat mass index; VFL, visceral fat level; BP, blood pressure; MVPA, moderate-vigorous physical activity

All models were additionally adjusted for sex in the total populations. *P* value < 0.05 are set in bold

LMI is mainly composed of skeletal muscle; the expansion of skeletal muscle tissue accompanying lean body mass growth consequently contributes to an augmentation in blood volume, thereby resulting in elevated blood pressure [38]. However, excessive skeletal muscle mass throughout the body has received little concern, so that its adverse effects on BP have been overlooked. Appropriate systemic skeletal muscle levels may be crucial for maintaining normal BP, especially ABP.

A previous study of 4,864 Korean adults proved that increased fat mass is related to an increased risk of hypertension [39]. In addition, fat mass plays a crucial role in influencing an individual's BP in obese and non-obese children [40]. Our findings are consistent with previous studies. Consider that fat mass and BP are influenced by some factors, such as physical activity and dietary habits/behavior. Therefore, we made a relatively comprehensive adjustment for potential confounding factors. In our study, we found that FMI was positively related to the risk of abnormal ABP and clinic BP. These findings may be partly explained by abnormalities in the RAAS, elevated insulin resistance, increased sympathetic tone, and release of inflammatory factors [41–43]. Besides, the relationship between VFL and abnormal ABP and clinic BP is statistically significant in this study. A review has demonstrated that excessive accumulation of visceral fat has been implicated in the pathogenesis of chronic inflammation and metabolic disorders, including elevated blood pressure [44]. In fact, the underlying mechanism of the positive correlation between VFL and BP is consistent with that of the positive correlation between FMI and BP, both stemming from abnormalities in the RAAS and the release of inflammatory factors [45]. Therefore, it might be important that FMI and VFL, as risk factors for abnormal BP, are controlled at reasonable levels to improve an individual's BP profiles.

Notably, the sex discrepancy in the relationship between body composition indicators and abnormal BP based on 24-hour ABPM was found in this study. In males, all body composition indicators exhibit a statistically significant association with abnormal ABP. However, in females, only LMI and VFL are significantly related to abnormal ABP. These findings suggest that different body composition indices may influence ABP patterns in a sex-specific manner. Because the default settings for daytime and nighttime ABPM may not accurately align with the participants' actual periods of activity and sleep. It is, therefore, critical to consider this difference, as diurnal BP rhythms are regulated by the autonomic nervous system, and various factors such as diet and physical activity can significantly influence ABP levels. Due to the variances in factors such as diet, physical activity, and other determinants between males and females, it is plausible that their circadian BP rhythms differ as well. Consequently, these differences in circadian BP patterns may influence the association between body composition and ABP. In addition, hormones like estrogen and testosterone have different effects on BP regulation [46]. For example, estrogen may have a protective effect on cardiovascular health in premenopausal females [46]. Furthermore, socioeconomic status can influence access to healthcare and preventive measures, which may differ between males and females [47]. Due to these variances, it is plausible that circadian BP rhythms differ between males and females, influencing the association between body composition indicators and ABP. However, the underlying mechanism for this difference is unclear. Future studies should aim to identify the underlying mechanisms contributing to this sex difference.

The strength of this study is to investigate the relationship between body composition and ABP in college students who are more representative of young Chinese groups. That's the novelty of our study. The outcomes of previous studies were mostly focused on clinic BP [48, 49]. Even though there are studies that concentrate on ABP, the population is based on older adults [35]. However, we also acknowledge some limitations in this study. Firstly, the type of study was cross-sectional, and a causal link between body composition and BP levels could not be determined. More cohort studies or intervention studies are needed to assess these relationships. Secondly, only participants ranging in age from 17 to 28 years were included in our study. Moreover, the study is largely relevant for Chinese youths $\leq$21 years old despite a small percentage of older participants. Therefore, we should be cautious when generating the findings for other age groups.

Conclusion

In conclusion, LMI, FMI, and VFL might be risk factors for abnormal BP based on 24-hour ABPM and clinic BP after adjusting for the potential covariates. In addition, our results indicate that there are significant sex differences in the association between body composition indicators (LMI, FMI, and VFL) and abnormal ABPM components. LMI, FMI, and VFL are all risk factors for abnormal BP based on ABPM in males, but in females, LMI and VFL are significantly associated with abnormal night-time BP. Our findings suggested maintaining an individual's appropriate muscle mass and fat mass and focusing on the different relations of males' and females' body composition is crucial for the achievement of appropriate BP profiles.

Acknowledgements
We would like to express our sincere gratitude to all the participants who took part in this study.

Author contributions

Bin Mao: Conceptualization, Data Curation, Formal Analysis, Methodology, Writing - Original Draft and Final Paper. Shengnan Li: Project administration, Resources, Supervision. Jixin Zhang: Data curation, Investigation, Validation. Zehui Fan: Conceptualization, Formal analysis, Methodology. Ying Deng: Data curation, Investigation. Hongjiao, Quan: Formal analysis, Methodology. Yide Yang: Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing.

Funding

This study was supported by the National Natural Science Foundation of China (No. 81903336), a project supported by the Scientific Research Fund of Hunan Provincial Education Department (No. 22B0038, 22C0025, and 22C0027), Scientific Research Project of Hunan Health Committee (No. 202112031516), Postgraduate Scientific Research Innovation Project of Hunan Province (QL20230133), and Hunan province college students research learning and innovative experiment project (S202410542075).

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author (yangyide2007@126.com) on reasonable request.

Declarations

Ethics approval and consent to participate

The current study was approved by the Medical Research Ethical Review Committee Board of Hunan Normal University (2019-88).

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no conflict of interest.

Received: 27 January 2024 / Accepted: 23 August 2024
Published online: 06 September 2024

References

1. VADUGANATHAN M, MENSAH G A, TURCO JV, et al. The Global Burden of Cardiovascular diseases and Risk: a compass for Future Health [J]. J Am Coll Cardiol. 2022;80(25):2361–71.
2. MILLS K T, BUNDY J D, KELLY T N, et al. Global disparities of hypertension prevalence and control: a systematic analysis of Population-Based studies from 90 countries [J]. Circulation. 2016;134(6):441–50.
3. Worldwide trends in. Hypertension prevalence and progress in treatment and control from 1990 to 2019: a pooled analysis of 1201 population-representative studies with 104 million participants [J]. Lancet. 2021;398(10304):957–80.
4. LU J, LU Y, WANG X et al. Prevalence, awareness, treatment, and control of hypertension in China: data from 1·7 million adults in a population-based screening study (China PEACE million persons project) [J]. Lancet (London, England), 2017;390(10112):2549–58.
5. WANG X, ZHOU HH, CHEN Z et al. Current status of hypertension prevalence, treatment and control rate among young and middle-aged population in China. Chin J Cardiol 2022;50(12):1169–76. [in Chinese]
6. OZEMEK C, LADDU D R, ARENA R, et al. The role of diet for prevention and management of hypertension [J]. Curr Opin Cardiol. 2018;33(4):388–93.
7. BÖRJESSON M, ONERUP A, LUNDQVIST S, et al. Physical activity and exercise lower blood pressure in individuals with hypertension: narrative review of 27 RCTs [J]. Br J Sports Med. 2016;50(6):356–61.
8. ZHOU W, SHI Y, LI Y Q, et al. Body mass index, abdominal fatness, and hypertension incidence: a dose-response meta-analysis of prospective studies [J]. J Hum Hypertens. 2018;32(5):321–33.
9. SIDOTI A, NIGRELLI S, ROSATI A, et al. Body mass index, fat free mass, uric acid, and renal function as blood pressure levels determinants in young adults [J]. Nephrol (Carlton Vic). 2017;22(4):279–85.
10. YE S, ZHU C, WEI C, et al. Associations of body composition with blood pressure and hypertension [J]. Obes (Silver Spring Md). 2018;26(10):1644–50.
11. YANO Y, VONGPATANASIN W. AYERS C, Regional Fat distribution and blood pressure level and variability: the Dallas Heart Study [J]. Hypertension (Dallas, Tex: 1979), 2016, 68(3): 576–83.
12. ZHAO, Q, ZMUDA J M, KUIPERS A L et al. Muscle Attenuation Is Associated With Newly Developed Hypertension in Men of African Ancestry [J]. Hypertension (Dallas, Tex: 1979), 2017, 69(5): 957 – 63.
13. BOSU W K, AHETO J M K ZUCCHELLIE, et al. Prevalence, awareness, and associated risk factors of hypertension in older adults in Africa: a systematic review and meta-analysis protocol [J]. Syst Reviews. 2017;6(1):192.
14. CHO H, KIM S M, JEONG SS, et al. Comparison of salt taste thresholds and salt usage behaviours between adults in Myanmar and Korea [J]. Asia Pac J Clin Nutr. 2016;25(4):879–84.
15. STAPLIN N, DE LA SIERRA A, RUILOPE L M, et al. Relationship between clinic and ambulatory blood pressure and mortality: an observational cohort study in 59 124 patients [J]. Lancet. 2023;401(10393):2041–50.
16. HUANG Q F, YANG W Y, ASAYAMA K et al. Ambulatory Blood Pressure Monitoring to Diagnose and Manage Hypertension [J]. Hypertension (Dallas, Tex: 1979), 2021, 77(2): 254 – 64.
17. FLYNN J T, URBINA E M, BRADY T M et al. Ambulatory Blood Pressure Monitoring in Children and Adolescents: 2022 Update: A Scientific Statement From the American Heart Association [J]. Hypertension (Dallas, Tex: 1979), 2022, 79(7): e114-e24.
18. ABRAMSON JL, LEWIS C, MURRAH NV. Body mass index, leptin, and ambulatory blood pressure variability in healthy adults [J]. Atherosclerosis. 2011;214(2):456–61.
19. YILMAZBAŞ P, HAŞLAK G V DURSUNH. The relationship between body fat ratio and blood pressure in school-age children [J]. J Hum Hypertens. 2020;34(12):826–32.
20. TORDJMAN T, LAMPERT S. The effect of intracoronary lidocaine infusion on acetylstrophanthidin-induced ventricular arrhythmia in dogs [J]. Pharmacotherapy. 1988;8(2):89–93.
21. YANG Y, XIE M, YUAN S, et al. Sex differences in the associations between adiposity distribution and cardiometabolic risk factors in overweight or obese individuals: a cross-sectional study [J]. BMC Public Health. 2021;21(1):1232.
22. YANG Y D, ZHENG C J, DONG Y H, et al. Sex difference in the mediation roles of an inflammatory factor (hsCRP) and adipokines on the relationship between adiposity and blood pressure [J]. Hypertens Research: Official J Japanese Soc Hypertens. 2019;42(6):903–11.
23. WHELTON P K, CAREY R M, ARONOW WS, et al. 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA Guideline for the Prevention, detection, evaluation, and management of high blood pressure in adults: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice guidelines [J]. J Am Coll Cardiol. 2018;71(19):e127–248.
24. PARATI G, STERGIOU G, O'BRIEN E, et al. European Society of Hypertension practice guidelines for ambulatory blood pressure monitoring [J]. J Hypertens. 2014;32(7):1359–66.
25. 2018. ESC/ESH guidelines for the management of arterial hypertension [J]. Revista espanola de cardiologia. (English ed). 2019;72(2):160.
26. KIM HL, LEE E M, AHN S Y, et al. The 2022 focused update of the 2018 Korean Hypertension Society Guidelines for the management of hypertension [J]. Clin Hypertens. 2023;29(1):11.
27. OMBONI S, ARISTIZABAL D, DE LA SIERRA A, et al. Hypertension types defined by clinic and ambulatory blood pressure in 14143 patients referred to hypertension clinics worldwide. Data from the ARTEMIS study [J]. J Hypertens. 2016;34(11):2187–98.
28. SHEN W, ZHANG T, LI S, Race and Sex Differences of Long-Term Blood Pressure Profiles From Childhood and Adult Hypertension: The Bogalusa Heart Study [J]., Hypertension et al. Dallas, Tex: (1979), 2017, 70(1): 66–74.
29. TOMITANI N, WANTHONG S, ROUBSANTHISUK W, et al. Differences in ambulatory blood pressure profiles between Japanese and Thai patients with hypertension /suspected hypertension [J]. J Clin Hypertens (Greenwich Conn). 2021;23(3):614–20.
30. COLAFELLA K M M, DENTON KM. Sex-specific differences in hypertension and associated cardiovascular disease [J]. Nat Rev Nephrol. 2018;14(3):185–201.
31. RECKELHOFF J J F. Gender differences in the regulation of blood pressure. Hypertens (Dallas Tex: 1979). 2001;37(5):1199–208.
32. LIU J, FOX C S, HICKSON D A, et al. Impact of abdominal visceral and subcutaneous adipose tissue on cardiometabolic risk factors: the Jackson Heart Study [J]. J Clin Endocrinol Metab. 2010;95(12):5419–26.

33. DRENOWATZ PRASADVK, HAND G A C, et al. Relation of body's lean Mass, Fat Mass, and body Mass Index with Submaximal systolic blood pressure in Young Adult men [J]. Am J Cardiol. 2016;117(3):394–8.
34. LI S, JIAO H, YANG J, et al. Association between lean body mass and hypertension: a cross-sectional study of 50 159 NHANES participants [J]. J Clin Hypertens (Greenwich Conn). 2023;25(10):957–64.
35. KORHONEN P E, MIKKOLA T, KAUTIAINEN H, et al. Both lean and fat body mass associate with blood pressure [J]. Eur J Intern Med. 2021;91:40–4.
36. SLETNER L, MAHON P, CROZIER S R et al. Childhood Fat and lean Mass: Differing relations to Vascular structure and function at Age 8 to 9 years [J]. Arteriosclerosis, thrombosis, and vascular biology, 2018, 38(10): 2528–37.
37. MEDINA-INOJOSA J R, SOMERS V K THOMASRJ et al. Association between Adiposity and lean Mass with Long-Term Cardiovascular events in patients with coronary artery Disease: No Paradox [J]. J Am Heart Association, 2018, 7(10).
38. JULIUS S, MAJAHALME S, NESBITT S, et al. A gender blind relationship of lean body mass and blood pressure in the Tecumseh study [J]. Am J Hypertens. 2002;15(3):258–63.
39. PARK S K, RYOO J H, OH C M, et al. Body fat percentage, obesity, and their relation to the incidental risk of hypertension [J]. J Clin Hypertens (Greenwich Conn). 2019;21(10):1496–504.
40. DROZDZ D, KWINTA P, KOROHODA P, et al. Correlation between fat mass and blood pressure in healthy children [J]. Pediatr Nephrol. 2009;24(9):1735–40.
41. KOTSIS V, STABOULI S. Mechanisms of obesity-induced hypertension [J]. Hypertens Research: Official J Japanese Soc Hypertens. 2010;33(5):386–93.
42. KALIL G Z, HAYNES W G. Sympathetic nervous system in obesity-related hypertension: mechanisms and clinical implications [J]. Hypertens Research: Official J Japanese Soc Hypertens. 2012;35(1):4–16.
43. CORKEY B E, DEENEY JT. Acyl CoA regulation of metabolism and signal transduction [J]. Prog Clin Biol Res. 1990;321:217–32.
44. SALIBA L J, MAFFETT S. Hypertensive heart disease and obesity: a review [J]. Heart Fail Clin, 2019, 15(4): 509–17.
45. LEITE N N, COTA B C GOTINEA, et al. Visceral adiposity index is positively associated with blood pressure: a systematic review [J]. Volume 15. Obesity research & clinical practice; 2021. pp. 546–56. 6.
46. CIGNARELLA A, BOLEGO C. Sex and sex steroids as determinants of cardiovascular risk [J]. Steroids. 2024;206:109423.
47. TADIRI C P, GISINGER T, KAUTZKY-WILLER A, et al. Determinants of perceived health and unmet healthcare needs in universal healthcare systems with high gender equality [J]. BMC Public Health. 2021;21(1):1488.
48. EJHEISHEH MA, BATRAN A, AYED A, et al. Correlation between anthropometric measurements and blood pressure in a population of Palestinian adults [J]. Sci Prog. 2022;105(2):368504221102782.
49. DEVONSHIRE A L, HAGER E R, BLACK M M, et al. Elevated blood pressure in adolescent girls: correlation to body size and composition [J]. BMC Public Health. 2016;16:78.

Publisher's note