

# The Interaction Effects of BMI and Dyslipidemia for Hypertension in Adults: A Cross-Sectional Survey

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## Research Article

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# Abstract

**Background:** Body mass index (BMI) is a commonly used international standard to measure body fat or thinness and health, and dyslipidemia is the metabolic abnormalities of lipoprotein in the human body, which are often considered have associated with high blood pressure. In this study, we explored the relationship between BMI or dyslipidemia and the risk of hypertension and further verified the possible interacting influences of BMI with dyslipidemia on the risk of hypertension. The aim is to explore the possible risk factors of hypertension and to provide scientific basis for the prevention and treatment of hypertension.

**Methods:** Eligible subjects were selected from a cross-sectional survey in Changsha City, and we collected relevant data and clinical indicators for each participant. Body mass index (BMI) was calculated as weight (kg)/height<sup>2</sup> (m<sup>2</sup>), and divided into four categories according to the Chinese standard. Dyslipidemia is defined according to Chinese guideline. The following indicators were used to assess the interaction effects: (1) Relative excess risk due to interaction (RERI); (2) Attributable proportion due to interaction (AP); (3) Synergy index (SI). SPSS software was used for statistical analysis.

**Results:** A total of 2740 eligible participants were enrolled in the cross-sectional study, of which 765 subjects (27.9%) were diagnosed with hypertension. Multivariate Logistic model showed that overweight or obese subjects had a significantly higher risk of hypertension than normal weight people, and low body weight was a protective factor for hypertension (OR: 0.52, 95% CI: 0.29-0.93). People with dyslipidemia have a higher risk of hypertension than those with normal lipids (OR: 3.05, 95% CI: 2.36-3.90). In addition, there was a significant interaction between overweight or obesity and dyslipidemia (overweight: RERI (1.91, 95% CI 0.17-3.66), AP (0.40, 95% CI 0.14-0.66), SI (2.03, 95% CI 1.11-3.74) and obesity: RERI (2.20, 95% CI 1.01-3.40), AP (0.38, 95% CI 0.18-0.58), SI (1.84, 95% CI 1.18-2.89), while no interaction was found between low body weight and dyslipidemia.

**Conclusion:** Low body weight is an independent protective factor for hypertension, but overweight, obesity and dyslipidemia are risk factors for hypertension, and dyslipidemia significantly shared interactions with overweight and obesity that influenced the risk of hypertension.

## Introduction

Hypertension affects more than one billion people worldwide, and that number is increasing, which makes it an increasingly serious public health problem worldwide<sup>[1]</sup>. In China, the prevalence of hypertension is high and rising, but the control rate is not satisfactory. Cardiovascular disease related to hypertension is still the main cause of death in Chinese adults<sup>[2]</sup>. A study shows that 44.7% of Chinese adults aged 35–75 suffer from hypertension<sup>[3]</sup>. Therefore, identifying the risk factors<sup>[3]</sup> of hypertension and effective prevention are essential to reduce the burden of public health.

At present, many studies have found that overweight, obesity and dyslipidemia are strongly associated with hypertension<sup>[4]</sup>. Excessive weight gain, especially weight gain associated with visceral fat gain, is the main risk of hypertension, accounting for 65–75% of the risk of human essential hypertension<sup>[5]</sup>, with the increase of body mass index (BMI), the risk of hypertension also increased. In addition, studies have proved that higher

BMI is a risk factor for hypertension and dyslipidemia<sup>[6]</sup>. Furthermore, dyslipidemia is common in patients with hypertension, diabetes mellitus, and metabolic syndrome<sup>[7]</sup>, and elevated serum levels of total cholesterol, LDL cholesterol, and non HDL cholesterol are all associated with an increased risk of hypertension<sup>[8]</sup>.

Hypertension as a disease with multifactorial influences, there may be interactions among various influencing factors to exert their influence on hypertension. Previous studies have shown that interaction between HbA1c and abdominal adiposity contributes to the development of hypertension<sup>[9]</sup>, the interaction between BMI and family history of hypertension has an impact on the risk of hypertension<sup>[10]</sup>, and there was a significant interaction between smoking and overweight with an impact on hypertension prevalence<sup>[11]</sup>. However, it is unknown whether there is an interaction between BMI and dyslipidemia to produce an effect on hypertension. Therefore, the present study, using data from this cross-sectional survey, aimed to investigate the association between BMI, dyslipidemia, and hypertension and to explore the potential interaction between BMI and dyslipidemia on the prevalence of hypertension.

## Methods

### Subjects

The survey was conducted in Changsha, Hunan Province, China from November 2019 to January 2020, with the aim of correctly assessing the major public health problems and their influencing factors in the city. The subjects were residents over 15 years old and multistage random sampling was used to select eligible subjects. Residents under 15 years of age, pregnant women, and residents with cognitive impairment, serious illness or disability that might affect the survey were not included in the survey, and all subjects signed the informed consent. On the day of enrollment, each subject underwent a cross-sectional survey, including a questionnaire, physical examination, and laboratory measurements. A total of 2,740 subjects with complete data were included by multi-stage cluster random sampling, ranging in age from 15 to 92 years (mean age:  $55.97 \pm 16.40$  years). Among them, a total of 765 patients with hypertension were investigated and classified as cases, and 1975 patients with normal blood pressure were classified as controls. Statistical analysis of the data was conducted to investigate risk factors and the interactions between these factors in patients with hypertension.

### Data collection

The questionnaire was designed with reference to the 2017 Questionnaire Specific for Social Factors Involved in the Prevention and Control of Chronic Diseases in China, and was conducted by qualified investigators using a face-to-face survey with the following main items: general information (gender, age, education level, etc.), smoking, drinking and eating conditions, physical activity, chronic disease awareness and treatment conditions. The physical examination included measurements of height, weight and waist circumference, which were measured using uniformly distributed instruments. Blood pressure was measured using a standard mercury sphygmomanometer (2mmHg per unit), and the subjects should avoid strenuous exercise, be mentally relaxed and quiet rest for 5 minutes before measurement. Each person was measured for 3 consecutive times, with the interval not less than 1 minute, and the average blood pressure of the three

times was taken. The blood collection was conducted by the field investigation team, and all subjects should fast for at least 8 hours. Hypertension was defined as follows: systolic blood pressure (SBP)  $\geq 140$  mmHg and/or diastolic blood pressure (DBP)  $\geq 90$  mmHg, or the patient is taking hypertensive medication<sup>[12]</sup>. Body mass index (BMI) was calculated as weight (kg)/height<sup>2</sup> (m<sup>2</sup>), and subjects were classified as underweight ( $< 18.5$  kg/m<sup>2</sup>), normal weight (18.5 to 23.9 kg/m<sup>2</sup>), overweight (24.0 to 27.9 kg/m<sup>2</sup>), or obese ( $\geq 28.0$  kg/m<sup>2</sup>) based on Chinese criteria<sup>[13]</sup>. Dyslipidemia was defined according to criteria of the 2007 Chinese Guidelines on Prevention and Treatment of Dyslipidemia in Adults<sup>[14]</sup>.

## Statistical methods

Statistical analysis was performed using SPSS software (version 20.0, IBM Corp, Armonk, NY, USA). Quantitative data with normal distribution was described by their mean  $\pm$  standard deviation, and the t-test was used for comparison between groups. Categorical data was expressed as percentages (%) and analyzed by chi-square test ( $\chi^2$  test). Unconditional logistic regression models are often used for dichotomous variables to explore the relationship between dependent and independent variables, and to determine the risk or protective factors of dependent variables. In this study, univariate logistic regression model was used to explore the significant factors affecting hypertension, and then these important factors were applied to multivariate logistic regression analysis by stepwise forward method. Meanwhile, the interaction between BMI and dyslipidemia was also analyzed and the following interactive indicators were calculated respectively: (1) the relative excess risk due to interaction (RERI); (2) attributable proportion due to interaction (AP); (3) the synergy index (SI)<sup>[15]</sup>. The 95% confidence interval (95% CI) of the interaction indicators were calculated using the table produced by T Anderson<sup>[16]</sup>. If the confidence interval of RERI or AP contains 0, or the confidence interval of SI contains 1, it indicates that the two factors have no interaction. All tests of statistical significance were two-tailed tests, and  $P < 0.05$  was considered statistically significant.

## Results

### General Characteristics of enrolled subjects

In this cross-sectional study, 2740 participants with a mean age of  $55.97 \pm 16.40$  years and a mean BMI of  $23.48 \pm 3.29$  kg/m<sup>2</sup> were included. 765 participants (27.9%) were found to have hypertension. Table 1 shows the basic characteristics of the study participants and prevalence of hypertension in different populations. As can be seen from the results in Table 1, there was a significant age difference in hypertension ( $P < 0.001$ ), and the prevalence of hypertension increased significantly with the increase of age (Fig. 1). There were also differences in the prevalence of hypertension among residents with different educational levels ( $P < 0.05$ ), and the prevalence of hypertension decreased with the increase of educational level. In addition, we found a higher prevalence of hypertension in patients with diabetes ( $P < 0.001$ ) and dyslipidemia ( $P < 0.001$ ). In terms of BMI, there were significant differences in the prevalence of hypertension among different BMI grades ( $P < 0.001$ ), and the prevalence of hypertension increased with the increase of BMI. However, no statistically significant differences were found for the following variables: gender ( $P = 0.772$ ), residence ( $P = 0.076$ ), smoking ( $P = 0.272$ ), and alcohol consumption ( $P = 0.564$ ).

Table 1  
Basic characteristic of the study participants

Variables	Hypertension(n,%)	Normal blood pressure(n,%)	t/χ <sup>2</sup>	P-value
Age (years,mean ± sd)	66.5 ± 10.5	51.9 ± 16.5	22.726 <sup>a</sup>	0.000
BMI(kg/m <sup>2</sup> ,mean ± sd)	24.5 ± 3.4	23.1 ± 3.2	9.886 <sup>a</sup>	0.000
Gender			0.084 <sup>b</sup>	0.772
Male	318(28.2)	809(71.8)		
Female	447(27.7)	1166(72.3)		
Age			353.739 <sup>b</sup>	0.000
15 ~ 44	28(4.0%)	670(96.0%)		
45 ~ 59	438(30.2%)	1014(69.8%)		
≥ 60	299(50.7%)	291(49.3%)		
Place of residence			5.158 <sup>b</sup>	0.076
city	522(26.8%)	1424(73.2%)		
rural	90(33.0%)	183(67.0%)		
The rural-urban junction	153(29.4%)	368(70.6%)		
Educational level			168.739 <sup>b</sup>	0.000
No formal schooling	21(35.0%)	39(65.0%)		
Primary school	247(44.0%)	315(56.0%)		
Junior high school	236(30.1%)	549(69.9%)		
High school	199(27.3%)	530(72.7%)		
College degree or above	62(10.3%)	542(89.7%)		
Smoking			1.205 <sup>b</sup>	0.272
Yes	197(29.6%)	469(70.4%)		
No	568(27.4%)	1506(72.6%)		
Drinking			0.333 <sup>b</sup>	0.564
Yes	142(29.0%)	348(71.0%)		
No	623(27.7%)	1627(72.3%)		

a student's t test;

Variables	Hypertension(n,%)	Normal blood pressure(n,%)	t/χ <sup>2</sup>	P-value
Diabetes			186.344 <sup>b</sup>	0.000
Yes	183(61.4%)	115(38.6%)		
No	582(23.8%)	1860(76.2%)		
Dyslipidemia			231.503 <sup>b</sup>	0.000
Yes	248(58.4%)	177(41.6%)		
No	517(22.3%)	1798(77.7%)		
BMI			85.903 <sup>b</sup>	0.000
Low weight	16(12.1%)	116(87.9%)		
The normal weight	341(22.9%)	1147(77.1%)		
Overweight	317(35.7%)	572(64.3%)		
Obesity	89(43.6%)	115(56.4%)		
a student's t test;				

b Chi-square test;

BMI: body mass index.

## Association between BMI or dyslipidemia and hypertension risk

The results of univariate Logistic regression analysis showed that people with a BMI of low weight(OR:2.60,95%CI:1.93–3.52), overweight(OR:5.61,95%CI:3.11–10.14), or obese(OR:1.40,95%CI:1.03–1.90) had a significantly higher risk of hypertension compared to normal weight. After adjusting for confounding factors including gender, age, diabetes, education and other levels, low body weight became a protective factor for hypertension(OR:0.52,95%CI:0.29–0.93), while overweight and obesity remained a risk factor for hypertension. In unifactorial logistic regression analysis, the risk of hypertension in people with abnormal blood lipids was significantly higher than that in people with normal blood lipids(OR:4.87,95%CI:3.93–6.05). After adjusting for confounding factors, the risk level was reduced, but it was still a risk factor for hypertension(OR:3.05,95%CI:2.36–3.90). (Table 2).

Table 2  
Independent effects of BMI and dyslipidemia on the risk of hypertension

Variables	Hypertension (n,%)	Normal blood pressure(n,%)	$\chi^2$	P-value	OR <sub>1</sub> <sup>a</sup> (95% CI)	OR <sub>2</sub> <sup>b</sup> (95% CI)
BMI			85.90	0.000		
The normal weight	341(22.9%)	1147(77.1%)			1.00(ref)	1.00(ref)
Low weight	16(12.1%)	116(87.9%)			2.60(1.93,3.52)	0.521(0.29,0.93)
Overweight	317(35.7%)	572(64.3%)			5.61(3.11,10.14)	1.70(1.39,2.09)
Obesity	89(43.6%)	115(56.4%)			1.40(1.03,1.90)	2.60(1.84,3.66)
Dyslipidemia			231.50	0.000		
Yes	248(58.4%)	177(41.6%)			4.87(3.93,6.05)	3.05(2.39,3.90)
No	517(22.3%)	1798(77.7%)			1.00(ref)	1.00(ref)
a OR <sub>1</sub> is the result of univariate analysis;						

b OR<sub>2</sub> is the result of multivariate analysis;

The adjusted confounding factors included gender, age, diabetes, education level and occupation.

## Interaction between BMI and dyslipidemia

Participants were divided into four groups based on their BMI levels: underweight, normal weight, overweight or obese. Compared with normal-weight individuals without dyslipidemia, those with dyslipidemia and obesity had the highest risk of hypertension (adjusted OR:5.82,95%CI:3.08–10.99), and those with dyslipidemia and overweight had a 4.77 times higher risk of hypertension than the reference group (Table 3).Furthermore, there were significant interactions between overweight or obesity and dyslipidemia(overweight:RERI (1.91,95%CI 0.17–3.66), AP (0.40,95%CI 0.14–0.66) ,SI (2.03,95%CI 1.11–3.74) and obesity:RERI (2.20,95%CI 1.01–3.40), AP (0.38,95%CI 0.18–0.58),SI (1.84,95%CI 1.18–2.89). However, the adjusted OR of dyslipidemia and low body weight was not statistically significant(2.37,95%CI:0.66–8.56), indicating that they had no statistical significance on the risk of hypertension, and the interaction indicators showed no additive interaction between the two (Table 4).

Table 3  
The interaction between BMI and dyslipidemia on the risk of hypertension

Variables		Hypertension (n,%)	Normal blood pressure(n,%)	OR <sub>1</sub> <sup>a</sup> ( 95% CI )	OR <sub>2</sub> <sup>b</sup> ( 95% CI )
Dyslipidemia	BMI				
No	The normal weight	253(19.3)	1061(80.7)	1.00(ref)	1.00(ref)
	Low weight	10(8.3)	111(91.7)	0.38(0.20,0.73)	0.43(0.22,0.87)
	Overweight	200(28.4)	503(71.6)	1.67(1.35,2.07)	1.49(1.18,1.88)
	Obesity	52(34.7)	98(65.3)	2.23(1.56,3.24)	2.26(1.50,3.39)
Yes	The normal weight	88(50.6)	86(49.4)	4.30(3.10,5.96)	2.36(1.64,3.39)
	Low weight	6(54.5)	5(45.5)	5.04(1.53,16.64)	2.37(0.66,8.56)*
	Overweight	117(62.9)	69(37.1)	7.12(5.13,9.88)	4.77(3.32,6.85)
	Obesity	37(68.5)	17(31.5)	9.17(5.06,16.49)	5.82(3.08,10.99)
a OR <sub>1</sub> is the result of univariate analysis;					
b OR <sub>2</sub> is the result of multivariate analysis;					
* Not statistically significant					
The adjusted confounding factors included gender, age, diabetes, education level and occupation.					

Table 4  
Indicators of interaction between BMI and dyslipidemia

Variables		RERI(95%CI)	AP(95%CI)	SI(95%CI)
Dyslipidemia	Low weight	-1.30(-4.80,2.20)	-0.55(-2.66,1.56)	0.51(0.05,5.13)
Dyslipidemia	Overweight	1.91(0.17,3.66)	0.40(0.14,0.66)	2.03(1.11,3.74)
Dyslipidemia	Obesity	2.20(1.01,3.40)	0.38(0.18,0.58)	1.84(1.18,2.89)
RERI:the relative excess risk due to interaction; AP:attributable proportion due to interaction; SI:the synergy index.				

## Discussion

Body mass index (BMI) is an important indicator of body fat and can correct for the effect of height on body mass. Studies have shown that BMI is the most sensitive physical measure to predict high blood pressure, compared with other common indicators of obesity<sup>[17]</sup>. There are a lot of research confirmed that in Chinese adults, overweight and obesity are important risk factors of hypertension<sup>[18,19]</sup>, overweight/obesity can

cause human body metabolism imbalance and hormone level changes resulting in high blood pressure<sup>[20]</sup>. At the same time, dyslipidemia is closely related to hypertension, dyslipidemia can change the permeability of cell membranes by affecting their structure, and can also cause renal microvascular damage, which can lead to hypertension<sup>[21]</sup>. Studies have shown that elevated levels of serum levels of total cholesterol (TC), low-density lipoprotein cholesterol (LDLC) and high-density lipoprotein cholesterol (HDLC) are associated with an increased risk of hypertension<sup>[22]</sup>.

The results of this study found that people with diabetes or dyslipidemia are at higher risk for hypertension, and that both overweight and obesity are risk factors for hypertension. This is similar to the findings of the Zhang FL's study, which found that individuals who are overweight/obese, have dyslipidemia or diabetes had a higher risk of developing hypertension<sup>[23]</sup>. Hashemi Madani N found that hypertension, dyslipidemia, and impaired fasting blood glucose were all likely to lead to an increase in adverse cardiovascular events<sup>[24]</sup>. de Lomberra Romero F found that hypertension was often associated with other atherosclerosis risk factors, such as dyslipidemia, insulin resistance and obesity<sup>[25]</sup>. What's more, Hu L found that in South China, the increase of age and BMI were the risk factors for hypertension<sup>[26]</sup>. In addition, the present study verified the additive interaction between dyslipidemia and overweight or obesity. Jian S's studies showed that triglyceride index and obesity had an interactive effect on the incidence of hypertension in middle-aged and elderly people, and dyslipidemia and obesity were both risk factors for hypertension<sup>[27]</sup>. Related studies have shown that dyslipidemia and overweight/obesity have several common mechanisms for increasing blood pressure, for example, dyslipidemia can impair arterial endothelial function, leading to hypertension<sup>[28]</sup>. Previous studies have proved that obesity and the cardiovascular disease family have an interactive effect on hypertension<sup>[29]</sup>. There is an interaction between dyslipidemia and oral contraceptives that can increase the risk of high blood pressure<sup>[30]</sup>. However, few studies have explored whether there is interaction between dyslipidemia and overweight/obesity on hypertension. Therefore, based on the findings in this study that overweight/obesity and dyslipidemia have interaction on hypertension, further studies on the interaction mechanism between these factors are needed in the future.

There are still some limitations in this study. For example, the information of bad behaviors such as smoking and drinking were obtained by asking the respondents, which may have information bias. In addition, the data analysis was based on cross-sectional studies, which could not distinguish time sequence and limited causal inference.

## Conclusion

In conclusion, low body weight is an independent protective factor for hypertension, but overweight, obesity and dyslipidemia are risk factors for hypertension. Moreover, dyslipidemia significantly shared interactions with overweight and obesity that influenced the risk of hypertension. Therefore, people who are overweight or obese and suffer from dyslipidemia are at higher risk of hypertension. It is very necessary that concrete measures should be taken in the early prevention and control of hypertension. What's more, lifestyle intervention and health guidance should be carried out as soon as possible, so as to reduce the incidence of hypertension in high-risk groups.

# Abbreviations

BMI  
Body mass index;RERI:Relative excess risk due to interaction;AP:Attributable proportion due to interaction;SI:Synergy index;OR:Odds ratio;CI:confidence interval.

# Declarations

## Acknowledgements

Not Applicable.

## Authors' contributions

All authors participated in this cross-sectional survey.NT and JM wrote the first draft of the paper and had equivalent contribution;JHZ,ZLL:designed the research,provided statistical guidance and revised the manuscript.NT,JM,ZLL,RQT,ZJC:acquisition and interpretation of data;NT,JM,YDY,QYH,YL,ZLL,JHZ:performed the statistical analysis;All authors read and approved the final manuscript.

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## Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Ethics approval and consent to participate

This study was approved by the Ethics Committee of Medical College of Hunan Normal University and was in accordance with standards set forth by the Declaration of Helsinki. Written informed consent was obtained from all participants(or their parent or legal guardian in the case of children under 18).

## Consent for publication

Not Applicable.

## Competing interests

All authors declare no conflicts of interest.

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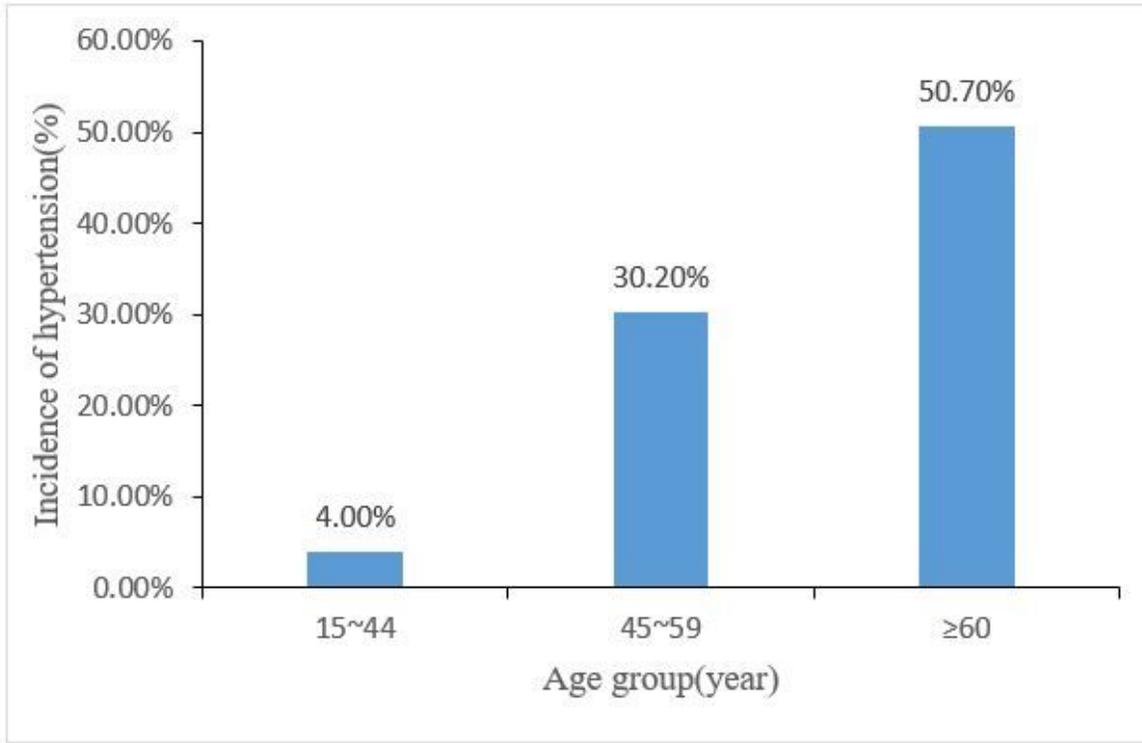
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## Figures



**Figure 1**

The prevalence of hypertension increases with age( $P < 0.05$ )