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The role of hypertension in mediating the relationship between overweight and obesity and diabetes: a longitudinal study

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Abstract

Background We aimed to assess the association of overweight and obesity with diabetes, and the mediating role of hypertension in this association, among Chinese adults.

Methods This longitudinal study comprised adults who had participated in at least three survey waves of the China Health and Nutrition Survey. We extracted data on blood pressure, height, weight, and self-reported doctor-diagnosed diabetes. Overweight and obesity, hypertension, and diabetes emerged successively if the above-mentioned condition launched. Logistic regression models were used to assess the longitudinal associations of overweight and obesity and hypertension with diabetes. Mediation analyses were performed to test hypertension as a potential mediator of the above associations.

Results In total, 6,996 adults [men: 46.2%; mean age (age range) at baseline: 39.5 (18–92) years] across China were included in this study. The combined prevalence of overweight and obesity at baseline was 41.5% (prevalence of overweight: 37.4%; prevalence of obesity: 4.1%). At a mean follow-up of 14.3 years, the incidence of hypertension and diabetes was 36.7% and 2.2%, respectively. The mean ages at onset of overweight and obesity, hypertension, and diabetes were 41.8, 53.4, and 56.1 years, respectively. Overweight and obesity and hypertension were independently associated with diabetes (all $P < 0.001$). Participants with overweight and obesity and hypertension were more likely to have subsequent diabetes than those without overweight and obesity and hypertension (odds ratio = 19.9; $P < 0.001$). Hypertension partially mediated the association between overweight and obesity and diabetes (percentage of mediation = 10.4%; $P < 0.001$).

Conclusion Our findings highlight the need for early identification of and immediate intervention for the disease chain of overweight and obesity, hypertension, and diabetes.

Keywords Overweight and obesity, Hypertension, Diabetes

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Background

Overweight and obesity are major public health challenges worldwide due to their rapidly increasing prevalence and the fact that they have reached pandemic proportions [1]. Accordingly, due to the increasingly obesogenic environment, overweight and obesity have become serious threats to the health of Chinese adults. Several major Chinese national surveys have shown that the prevalence of overweight and obesity has increased rapidly in recent years [2]. Obesity affects a large number of Chinese adults, with a report estimating this number to be approximately 85 million [3].

In addition to being recognized as chronic diseases, overweight and obesity are identified as risk factors for hypertension, diabetes, cardiovascular disease, and cancers [4]. Due to the driving effect of overweight and obesity, the prevalence of hypertension and diabetes has also been at high levels in China [5, 6]. Based on the population attributable risk, overweight and obesity accounts for 44.6% of incident hypertension and a large proportion of incident diabetes (women: 48.6%; men: 41.5%) in China [7, 8]. Of note, the disease cluster of overweight and obesity, hypertension, and diabetes was found to be one of the most prevalent multimorbidity patterns among Chinese adults [9]. This multimorbidity epidemic has led to increased healthcare utilization, poorer quality of life, and premature death [10].

To facilitate effective prevention, intervention, and management of the disease cluster, it is crucial to understand its occurrence and progression patterns. Previous studies in China have reported that overweight and obesity, hypertension, and diabetes occur successively, as indicated by the mean ages at their onset [11]. Another study in China pointed out that overweight and obesity can predict hypertension–diabetes comorbidity [12]. Given that hypertension precedes diabetes in terms of the mean age at onset, some researchers in other countries have assessed the mediating role of hypertension in the relationship between overweight and obesity and diabetes [13]. However, such investigations with a longitudinal design in the Chinese population are lacking. Therefore, using data from the China Health and Nutrition Survey (CHNS), a nationwide longitudinal study, this study aimed to assess the relationship between overweight and obesity and diabetes, and the mediating role of hypertension in this relationship, among Chinese adults.

Methods

Study population

The CHNS was a population-based, nationwide, longitudinal observational study from 1989 to 2015, the data of which were published recently [14]. During the above-mentioned period, 10 survey waves (survey years 1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011 and 2015) were conducted [14]. The mean interval between the consecutive survey waves was 2.7 years. A multistage, random-cluster method was used to select the sample from China. In each survey wave, the participants answered questionnaires and underwent physical examinations. The study was conducted in accordance with the Declaration of Helsinki. This study was approved by the Institutional Review Boards of the University of North Carolina at Chapel Hill and the Institute of Nutrition and Health, Chinese Center for Disease Control and Prevention. All participants provided written informed consent.

Given the longitudinal design of the CHNS, we assumed that overweight and obesity, hypertension, and diabetes emerged successively in the order of the survey waves, which provides a clear temporal relationship. Consequently, this longitudinal study only included those participants who had participated in at least three survey waves. The CHNS dataset includes 11,528 adults who had completed at least three survey waves and were not pregnant and whose complete and accurate data on age, gender, survey wave, height, weight, and blood pressure were recorded. Of these participants, 4,532 were excluded due to ineligibility, and the remaining 6,996 participants were included in the current study (inclusion and exclusion of participants in Supplementary Material). The study flowchart is provided in Supplementary Material (Figure S1). To facilitate statistical analysis in the present study, we defined the baseline survey as the survey wave in which a participant's overweight and obesity was first recorded, or the first survey wave for a participant who did not have overweight and obesity across the study period, and the final survey was defined as the survey wave in which a participant's diabetes was first recorded, or the last survey wave for a participant who did not have diabetes across the study period. In addition, participants with onset of hypertension in the baseline survey or final survey were excluded.

Exposure

Participants' weight in light clothing and height without shoes were measured by trained interviewers using a calibrated floor scale and a portable stadiometer, respectively, in each survey wave. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. The recommend criteria to identify Chinese adults with overweight and obesity (BMI $\geq 24\ kg/m^2$) were used in this study [15]. The age when overweight and obesity first appeared was considered as the age at onset of overweight and obesity.

Mediator

Participants' blood pressure was measured in a seated position by trained interviewers using standard mercury sphygmomanometers with appropriately sized cuffs. In

each survey wave, BP was measured three times on the right arm. The mean of the three measurements was used for further analysis. Hypertension was defined as systolic/diastolic BP ≥ 140/90 mmHg or self-reported use of antihypertensive medications [16]. The age when hypertension first appeared was considered as the age at onset of hypertension.

Outcome

Data on diabetes were collected using a structured questionnaire. The questions "Has a doctor ever told you that you suffer from diabetes?" and "How old were you (in years) when the doctor told you this?" were used in the questionnaire to define diabetes and its age of onset, respectively. Participants who were told by their doctors that they had diabetes and who provided their age at which the doctor told them this were considered to have self-reported doctor-diagnosed diabetes. The first recorded of the latter was considered as the age at onset of diabetes. Participants who were told by their doctors that they had no diabetes, participants whose information regarding the above-mentioned first question were missing, and participants who were told by their doctors that they had diabetes but whose information regarding onset age were missing, were considered to have no self-reported doctor-diagnosed diabetes.

Covariates

Data on gender (male/female), age, ethnicity (Han nationality/others), residence (urban/rural residence), education level, marital status (never married/married/divorced, separated, widowed), alcohol intake, smoking, fat intake, leisure time physical activity, and household asset score were collected using a questionnaire [17]. The questions on and definitions of alcohol intake, smoking, fat intake, leisure time physical activity, and household asset score are provided in detail in Supplementary Table S1. The length of follow-up was calculated as the difference between the age at the final survey and the age at the baseline survey if diabetes did not emerge across the study period, and as the difference between the age at onset of diabetes and the age at the baseline survey if diabetes emerged in a survey. The missing data on continuous and categorical covariates, except sex and age, were imputed using the mean and mode imputation methods, respectively [17].

Statistical analysis

We used logistic regression models to investigate the association between overweight and obesity at the baseline survey and incident hypertension. Model 1 was constructed without adjustment for covariates. Model 2 was adjusted for baseline covariates (gender, age, ethnicity, residence, education level, marital status, alcohol intake, smoking, fat intake, leisure time physical activity, survey wave, and household asset score), and the length of follow-up for hypertension. Similar strategies and logistic regression models were used to assess the independent associations of overweight and obesity and hypertension with diabetes. We also used logistic regression models adjusted for covariates to assess the combined influence of overweight and obesity and hypertension on diabetes.

Mediation models were constructed to examine whether the association between overweight and obesity and diabetes was mediated by hypertension. The mediation package in R 4.3.2 was used to perform all mediation analyses [18]. The mediation analyses included two models (model 1 and model 2). Model 1 assessed the association of overweight and obesity with hypertension. Model 2 evaluated the association of overweight and obesity and hypertension with diabetes. Multivariable logistic regression was conducted in both model 1 and model 2. Regression coefficients were obtained based on the above-mentioned logistic models. Subsequently, the total effect, average causal mediation effect (ACME), average direct effect (ADE), and proportion of mediation were obtained from the mediation analyses [18]. Partial or complete mediation was determined based on the *P* values of ACME and ADE.

To assess the robustness of our findings, we (1) conducted subgroup analyses by gender (male/female), baseline mean age (≥ 39.5/<39.5 years), and residence (urban/rural residence); (2) repeated the mediation models after excluding participants with baseline obesity (BMI ≥ 28 kg/m^2); (3) identified the participants with overweight and obesity onset after the first wave and repeated the mediation models after excluding these participants with new-onset overweight and obesity; (4) repeated the mediation models after excluding participants whose baseline surveys were conducted in the 1991 or 1993 waves; and (5) repeated the mediation models after using waist circumference (WC) to assess excess weight (men: WC ≥ 85 cm; women: WC ≥ 80 cm) [15].

Statistical analyses were performed using SAS 9.4 (SAS Institute, Cary, NC, USA) and R 4.3.2. Two-sided *P* values < 0.05 were considered statistically significant.

Results

Table 1 presents the baseline characteristics of all participants. In total, 6,996 eligible participants at baseline [men: 46.2%; mean age (age range) at baseline: 39.5 (18–92) years; Han nationality: 86.7%] were included in this study. The combined prevalence of overweight and obesity at baseline was 41.5% (prevalence of overweight: 37.4%; prevalence of obesity: 4.1%). The mean age of participants with overweight and obesity at baseline was 41.8 years. At a mean follow-up period of 14.3 years, the incidence of hypertension and diabetes was 36.7% and 2.2%,

Table 1 Baseline characteristics of the participants (*N* = 6996)

	Mean (SD)	No. (%)
Male participants, n (%)		3232 (46.2)
Age (years)	39.5 (13.5)	
Han Nationality, n (%)		6068 (86.7)
Having leisure physical activity, n (%)		168 (2.4)
Urban residence, n (%)		2260 (32.3)
Completed Upper middle school and above, n (%)		1475 (21.1)
Survey wave, n (%)		
1991		2783 (39.8)
1993		618 (8.8)
1997		1113 (15.9)
2000		956 (13.7)
2004		721 (10.3)
2006		392 (5.6)
2009		413 (5.9)
Marital status, n (%)		
Never married		803 (11.5)
Married		5912 (84.5)
Divorced/Separated/Widowed		281 (4.0)
Household asset score	2.2 (1.8)	
Fat intake (g/day)	68.5 (45.9)	
Drinking, n (%)		2412 (34.5)
Past/Current Smoker, n (%)		2222 (31.8)
BMI (kg/m^2)	22.4 (3.2)	
Overweight and obesity, n (%)		2905 (41.5)
SBP (mm Hg)	112.2 (11.8)	
DBP (mm Hg)	73.2 (8.2)	

Data were shown as means (SDs) and number (%) for continuous and categorical variables, respectively

BMI body mass index, *DBP* diastolic blood pressure, *SBP* systolic blood pressure

Table 2 Interrelationship between overweight and obesity, hypertension and diabetes

	Model 1		Model 2	
	Crude OR (95% CI)	*P*	Adjusted OR (95% CI)	*P*
Outcomes: Hypertension*				
Overweight and obesity	2.27 (2.05, 2.50)	<0.001	3.14 (2.72, 3.63)	<0.001
Outcomes: Diabetes**				
Overweight and obesity	6.26 (4.07, 9.61)	<0.001	7.74 (4.88, 12.29)	<0.001
Hypertension	2.09 (1.49, 2.92)	<0.001	2.34 (1.58, 3.46)	<0.001

OR odds ratio, *CI* confidence interval

*Adjusted baseline characteristics (gender, age, Han nationality, leisure physical activity, urban residence, completed upper middle school and above, survey wave, marital status, household asset score, fat intake, drinking, and past/current smoking), and the length of follow-up for hypertension

**Adjusted above-mentioned baseline characteristics and the length of follow-up

Table 3 Combined effect of overweight and obesity and hypertension on diabetes

	Incidence of diabetes, %	Model 1		Model 2	
		Crude OR (95% CI)	*P*	Adjusted OR (95% CI)*	*P*
Overweight and obesity/Hypertension					
No/No (n=2913)	0.45	Ref		Ref	
No/Yes (n=1178)	1.10	2.49 (1.15, 5.38)	0.021	3.00 (1.33, 6.76)	0.008
Yes/No (n=1516)	3.03	6.98 (3.76, 12.96)	<0.001	9.00 (4.73, 17.13)	<0.001
Yes/Yes (n=1389)	5.90	13.99 (7.77, 25.21)	<0.001	19.90 (10.55, 37.55)	<0.001

OR odds ratio, *CI* confidence interval

*Adjusted baseline gender, age, Han nationality, leisure physical activity, urban residence, completed upper middle school and above, survey wave, marital status, household asset score, fat intake, drinking, and past/current smoking, and the length of follow-up

respectively, and the mean age at onset was 53.4 and 56.1 years, respectively. The average interval from the onset of overweight and obesity to the incidence of hypertension, from the onset of hypertension to the incidence of diabetes, and from the onset of overweight and obesity to the incidence of diabetes was 11.6, 2.7, and 14.3 years, respectively. Supplementary Table S2 shows the ages at onset of overweight and obesity, hypertension, and diabetes stratified by different development patterns.

Table 2 summarizes the interrelationships between overweight and obesity, hypertension, and diabetes. Overweight and obesity [odds ratio (95% confidence interval), OR (95% CI): 2.27 (2.05, 2.50); $P<0.001$] were significantly related to incident hypertension. After adjusting for covariates, similar results were obtained. Additionally, overweight and obesity [OR (95% CI): 6.26 (4.07, 9.61); $P<0.001$] and hypertension [OR (95% CI): 2.09 (1.49, 2.92); $P<0.001$] were independently and positively related to incident diabetes. The results did not change significantly after adjusting for covariates.

Table 3 shows the combined effects of overweight and obesity and hypertension on incident diabetes. The incidence of diabetes was 0.45%, 1.10%, 3.03%, and 5.90% in participants without overweight and obesity and hypertension, those without overweight and obesity but with hypertension, those with overweight and obesity but without hypertension, and those with overweight and obesity and hypertension, respectively. Participants without overweight and obesity but with hypertension, those with overweight and obesity but without hypertension, and those with overweight and obesity and hypertension were more likely to have diabetes than those without overweight and obesity and hypertension (all $P<0.01$).

Table 4 reports the mediating effect of hypertension on the association between overweight and obesity and diabetes. We noted a mediating role of hypertension in the association between overweight and obesity and diabetes (percentage of mediation = 10.4%; $P < 0.001$). We conducted subgroup and sensitive analyses for the mediating role of hypertension (Fig. 1; Supplementary Tables S3–S12) and obtained similar results as those described above (Fig. 1; Supplementary Tables S3–S12).

Table 4 Mediation effect of hypertension on the association of overweight and obesity with diabetes*

	β (SE)	Estimation (95%CI)	*P*
Model 1			
Overweight and obesity→ hypertension	1.29 (0.07)		<0.001
Model 2			
Overweight and obesity→ diabetes	2.05 (0.24)		<0.001
Hypertension→ diabetes	0.85 (0.20)		<0.001
Average causal mediation effects		0.0046 (0.0024, 0.01)	<0.001
Average direct effects		0.0414 (0.0319, 0.05)	<0.001
Total effects		0.0460 (0.0361, 0.06)	<0.001
Percentage of Mediation, %		10.4 (5.5, 15.0)	<0.001

*Adjusted baseline gender, age, Han nationality, leisure physical activity, urban residence, completed upper middle school and above, survey wave, marital status, household asset score, fat intake, drinking, and past/current smoking, and the length of follow-up; *β*, regression coefficient; CI confidential interval

Discussion

In this nationwide longitudinal study, we confirmed the independent associations of overweight and obesity and hypertension with diabetes. Participants with overweight and obesity and hypertension were more likely to have diabetes than those without overweight and obesity and hypertension. Further, a mediating role of hypertension in the association between overweight and obesity and diabetes was observed.

Multimorbidity of overweight and obesity, hypertension, and diabetes has become increasingly common [9]. In this disease cluster, overweight and obesity tend to emerge first [9]. Previous studies have found that hypertension and diabetes emerge successively after the onset of overweight and obesity. A cross-sectional study reported that the mean ages at onset of hypertension and diabetes were 55.4 and 56.7 years, respectively [11]. Similarly, our longitudinal study indicated that the mean ages at onset of overweight and obesity, hypertension, and diabetes were 41.8, 53.4, and 56.1 years, respectively. This order of onset suggests a potential causal association between overweight and obesity, hypertension, and diabetes.

Overweight and obesity may trigger the subsequent associated diseases. The findings of the current study confirmed that overweight and obesity were related to

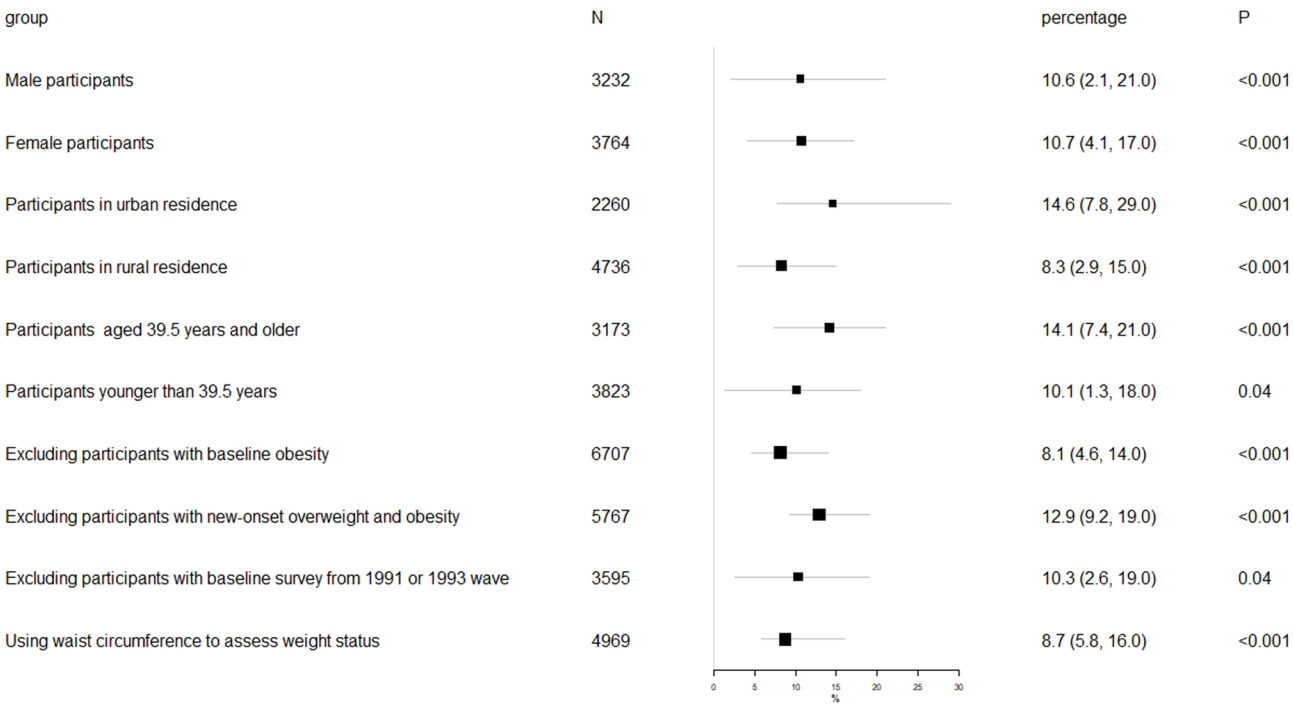

Fig. 1 Subgroup/sensitive analyses for percentage of mediation about hypertension

incident hypertension and diabetes. A large body of evidence also shows similar results [19, 20]. A cross-sectional study from the Bangladesh Demographic and Health Survey showed that overweight and obesity were significantly related to hypertension–diabetes comorbidity, which was consistent with another cohort study in China [12, 21]. Causal relationships between overweight and obesity and hypertension, diabetes, and hypertension–diabetes comorbidity are well-established and widely accepted. However, the association between hypertension and diabetes has been inconclusive. A meta-analysis indicated that hypertension predicated the incidence of diabetes [22]. A study based on the CHNS demonstrated that the long-term systolic BP trajectory predicted incident diabetes [23]. A Mendelian randomization study demonstrated that individuals with elevated systolic BP had an increased risk of type 2 diabetes relative to those with normal systolic BP [24]. In agreement with the above-mentioned studies, this study showed a significant independent association between hypertension and diabetes.

Our study also revealed that participants with overweight and obesity and hypertension were more likely to have incident diabetes than those without overweight and obesity and hypertension. An Australian longitudinal study of women's health also found that the cumulative incidence of diabetes was 36.8% in women with hypertension and obesity [25]. In another study, rural participants in Northeast China with hypertension and general or central obesity tended to be more likely to have diabetes relative to those without hypertension and obesity, which is consistent with our findings [26].

Overweight and obesity, hypertension, and diabetes are common, identifiable, and reversible conditions when occurring individually. In comparison, multimorbidity of these conditions poses greater health risks and is harder to manage [10]. For example, studies have reported that participants with hypertension and subsequent diabetes have higher risks of cardiovascular disease and that the use of anti-hypertensive medications, including β-blockers and diuretics, is associated with an increased risk of diabetes [27, 28]. Consequently, it is important to understand the occurrence of and interrelationship between overweight and obesity, hypertension, and diabetes over time for the prevention and control of this disease chain. Our study demonstrated the mediating role of hypertension in the association between overweight and obesity and diabetes. Additionally, a partial mediation was noted, with the proportion of mediation being 10.4%, which suggests that only 10.4% of the individuals with overweight and obesity in the study sample had diabetes mediated by hypertension. In Line with our results, a cross-sectional study showed that 18.6% of the total effect of overweight and obesity on diabetes was mediated through hypertension [13]. Our study demonstrated a similar degree of the mediating effect of hypertension on the overweight/obesity–diabetes association stratified by gender (male/female), baseline mean age (≥39.5/<39.5 years), and residence (urban/rural residence) (Supplementary Table S3, S4, S9, S10, S11, and S12). Additionally, WC can provide information on fat distribution. Thus, using WC as a measure of excess weight, we aimed to investigate the percentage of mediation by hypertension in the association between excess weight defined WC and diabetes. The results showed that hypertension played a partial mediating role in the association between excess weight defined by WC and diabetes, and the percentage of mediation was 8.7% (Supplementary Table S8).

Several explanations of our findings can be hypothesized. First, the effect of overweight and obesity on hypertension by increased sympathetic nervous system activity, adipokines, insulin resistance, systemic inflammation, the renin–angiotensin–aldosterone system, and other potential mechanisms is well-established [19]. Second, overweight and obesity induce the onset of diabetes through insulin resistance and β-cell dysfunction [20]. Finally, the link between hypertension and diabetes depends mainly on vasoconstriction, insulin resistance, and inflammation [13, 24].

Our findings have important implications for public health policy. First, our findings suggest that primordial prevention is the most important strategy for the prevention of overweight and obesity and associated complications, which emphasizes the importance of preventing the occurrence and epidemic of overweight and obesity at the population level. Shaping health environments, strengthening health education, and promoting healthy lifestyles are also crucial [4]. Second, weight loss is an essential step in controlling the development of the disease chain (e.g. hypertension onset) in adults with overweight and obesity [29]. Finally, dynamic monitoring, including remote monitoring based on digital health tools, can provide opportunities for early identification and interventions to prevent new disease onset (e.g. diabetes) and more disease clusters among adults with overweight and obesity and associated conditions (e.g. hypertension) [30]. As for the clinical implications of this study, clinicians are recommended to provide early, effective, and timely interventions to prevent and control the disease chain of overweight and obesity and related diseases (e.g. hypertension).

This study has several strengths including a large population, a longitudinal study design, and a rigorous data collection process. Nevertheless, some limitations should be noted. First, information regarding self-reported doctor-diagnosed diabetes may be inaccurate, which may have introduced recall or reporting bias. The incidence of self-reported doctor-diagnosed diabetes tended to be

lower than the true incidence. Consequently, the overweight/obesity–diabetes association and the mediating role of hypertension in this association may have been underestimated. Future studies using objective measurements of diabetes are needed to confirm our results. Second, the CHNS did not collect information regarding diabetes in the 1991 and 1993 waves, and therefore, we could not exclude participants with self-reported doctor-diagnosed diabetes in these waves. However, despite the low self-reported doctor-diagnosed incidence of diabetes, our relevant sensitivity analysis results did not change significantly after excluding participants included in the 1991 or 1993 waves (Supplementary Table S7). Third, we considered the survey wave when a participant's overweight and obesity was first recorded as their baseline survey to facilitate statistical analysis, which may have affected our findings. We excluded the participants with overweight and obesity onset after the first wave and repeated the mediation models. We observed the similar results (Supplementary Table S6). Fourth, only a small number of participants had obesity in this study. Consequently, we repeated the mediation models after excluding participants with baseline obesity (Supplementary Table S5). The association of obesity with hypertension and diabetes could not be properly assessed. Fifth, this study did not consider diabetes as a mediator because hypertension generally precedes diabetes, as indicated by the mean ages at their onset in China, and because the incidence of diabetes was low in the current study (2.2%). Future studies are needed to assess the mediating role of diabetes in the association of overweight and obesity with hypertension. Sixth, this study used BMI to assess weight status. However, BMI does not differentiate between muscle and fat mass and thus may not accurately reflect metabolic health in all individuals. In contrast, WC provides information on fat distribution. A partial mediating effect of hypertension on the association of excess weight with diabetes was noted regardless of the BMI or WC. Seventh, potential biases due to loss to follow-up are unavoidable due to the longitudinal design of this study. Thus, significant differences were observed in some baseline characteristics between the participants in the current study and those who were lost to follow-up (Supplementary Table S13). Finally, some covariates were not adjusted in the mediation models in the subgroup and sensitive analyses (e.g. Supplementary Tables S3) due to model fitting, which may have affected our findings.

Conclusions

In conclusion, this study showed the significant effect of overweight and obesity and hypertension on incident diabetes. Our study emphasizes the importance of early identification of and immediate intervention in the disease chain of overweight and obesity, hypertension, and diabetes.

Abbreviations

BMI	body mass index
WC	waist circumference
CHNS	China Health and Nutrition Survey

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-025-24685-x.

Supplementary Material 1.

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Authors' contributions

HF and HC conceptualized and designed the study. HF carried out the initial analyses, drafted the initial manuscript and reviewed and revised the manuscript; XZ and HC critically reviewed and revised the manuscript; and all authors approved the final manuscript as submitted.

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Data availability

The datasets generated and/or analyzed during the current study are publicly available in the https://www.cpc.unc.edu/projects/china/data/datasets/data-downloads-registration.

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki. This study was approved by the Institutional Review Boards of the University of North Carolina at Chapel Hill, and the Institute of Nutrition and Health, China Center for Disease Control and Prevention. All of the participants provided signed informed consent.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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