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Associations of BMI–Waist Circumference Phenotypes With Hypertension and Cardiometabolic Outcomes among U.S. Adults: NHANES 2015-2018

Juntao He

Faculty of Science and Technology, Beijing Normal-Hong Kong Baptist University, Zhuhai, China
2167673445@qq.com

Abstract. Body Mess Index (BMI) may classify some adults as normal weight even when excess abdominal adiposity is present, potentially masking an unfavorable cardiometabolic profile. We investigated this discordance by examining four BMI–waist circumference phenotypes in 9,867 adults participating in NHANES 2015–2018. Hypertension was the primary outcome, with diabetes and low HDL-C evaluated as secondary outcomes. Associations were estimated using logistic regression that incorporated the NHANES survey design and sequential adjustment for demographic, socioeconomic, and lifestyle characteristics. Relative to adults with normal BMI and normal waist circumference, those with normal-weight central obesity had greater odds of hypertension after full adjustment (OR 2.12, 95% CI 1.13–4.00). Higher odds of low HDL-C were also observed in this phenotype, whereas the association with diabetes was not statistically significant. These results suggest that BMI and waist circumference capture different aspects of adiposity and that considering both measures may better identify normal-weight adults with elevated cardiometabolic burden.

Keywords: body mass index, waist circumference, normal-weight central obesity, hypertension, cardiometabolic risk

1. Introduction

Nowadays Body mass index (BMI) is the most widely used measure for classifying overweight and obesity in clinical practice and population research. However, BMI does not distinguish fat mass from lean mass or capture the distribution of adipose tissue, and individuals with similar BMI values may have substantially different cardiometabolic risk profiles. Waist circumference (WC), a practical marker of abdominal adiposity, provides risk information beyond BMI, and expert consensus has recommended incorporating measures of central obesity into obesity-related risk assessment [1]. More recently, the *Lancet Diabetes & Endocrinology Commission* emphasized that BMI alone provides insufficient information about obesity, and individual health status, and also recommended complementary measures, including WC [2].

A clinically important consequence of relying solely on BMI is the potential misclassification of individuals with normal-weight central obesity (NWCO)—that is, those whose BMI falls within the

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normal range despite elevated abdominal adiposity. In NHANES III, normal-weight central obesity was associated with increased cardiovascular mortality [3]. A large population-based study from China also found higher odds of hypertension among adults with normal BMI but central obesity compared with those with normal BMI and normal WC [4]. Furthermore, an analysis of US NHANES data reported that NWCO was associated with higher odds of diabetes, supporting the presence of broader metabolic abnormalities in this phenotype [5]. Nevertheless, the cardiometabolic features of NWCO relative to the full spectrum of BMI–WC phenotypes remains less well characterized, particularly with hypertension as the primary outcome in a nationally representative US population.

Therefore, using NHANES 2015-2018, we compared prevalent hypertension across four mutually exclusive BMI–WC phenotypes: normal weight without central obesity, normal-weight central obesity, BMI-defined overweight/obesity without central obesity, and BMI-defined overweight/obesity with central obesity. We also examined diabetes and low high-density lipoprotein cholesterol as secondary cardiometabolic outcomes. By evaluating BMI and WC jointly, this study aimed to determine whether BMI-based classification alone may overlook a subgroup of normal-weight adults with elevated cardiometabolic burden and to clarify the potential value of waist circumference as a complementary measure for risk stratification.

2. Methods

2.1. Study design and data source

Data were obtained from the 2015–2016 and 2017–2018 cycles of the National Health and Nutrition Examination Survey (NHANES), which samples the US civilian population using a multistage probability design. Relevant demographic, questionnaire, examination, and laboratory datasets were merged by the unique participant identifier (SEQN). The two survey cycles were pooled for analysis, with the NHANES sampling structure incorporated into subsequent weighted analyses. NHANES data collection was approved by the National Center for Health Statistics Ethics Review Board, and informed consent was obtained from all participants [6].

2.2. Study population

Adults aged 18 years or older who participated in NHANES 2015-2018 were included. Participants were required to have completed the MEC examination and to have valid measurements of both body mass index (BMI) and waist circumference (WC). Participants with confirmed pregnancy were excluded because pregnancy substantially alters body weight and abdominal circumference. Individuals with BMI <18.5 kg/m² were also excluded so that the analytic framework focused on normal weight and BMI-defined overweight/obesity phenotypes without combining underweight participants with the reference category.

Participants were additionally excluded if they lacked valid survey examination weights, primary sampling unit information, or strata information, or if hypertension status could not be determined from available blood pressure measurements or antihypertensive medication information.

2.3. BMI–waist circumference phenotypes

BMI and waist circumference were based on measurements obtained during the NHANES mobile examination center assessment. BMI was derived from measured height and weight, while waist

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circumference was recorded in centimeters following the NHANES anthropometric protocol [7]. Participants with BMI values from 18.5 to <25.0 kg/m² were classified as normal weight, whereas those with BMI ≥25.0 kg/m² were classified as overweight/obese. Central obesity was defined as a waist circumference of ≥102 cm for men or ≥88 cm for women [1].

Combining BMI category with central obesity status yielded four mutually exclusive phenotypes: normal weight without central obesity, normal-weight central obesity (NWCO), overweight/obesity without central obesity, and overweight/obesity with central obesity. The first group served as the reference category, and NWCO was the primary phenotype of interest.

2.4. Outcome definitions

Hypertension was the primary outcome. For participants with available blood pressure data, mean systolic blood pressure (SBP) and diastolic blood pressure (DBP) were calculated from all valid examination readings. Participants were classified as hypertensive if the mean SBP was ≥130 mmHg, the mean DBP was ≥80 mmHg, or they reported current use of antihypertensive medication [8]. Those below both blood pressure thresholds and not using antihypertensive medication were classified as non-hypertensive.

Diabetes and low high-density lipoprotein cholesterol (HDL-C) were evaluated as secondary outcomes. Diabetes was identified by self-reported physician diagnosis or current use of insulin or glucose-lowering medication. Low HDL-C was defined as <40 mg/dL in men and <50 mg/dL in women [9].

For sensitivity analysis, hypertension was redefined using a threshold of ≥140 mmHg for mean SBP or ≥90 mmHg for mean DBP, while retaining current antihypertensive medication use as an additional criterion.

2.5. Covariates

Adjustment variables were chosen before analysis based on their relevance to adiposity and cardiometabolic outcomes. The models included age, sex, race/ethnicity, educational attainment, family income-to-poverty ratio (PIR), smoking status, alcohol use, physical activity, and NHANES survey cycle. Age and PIR were treated as continuous variables, whereas race/ethnicity, education, and smoking status were modeled categorically.

Alcohol use was harmonized across the two survey cycles as any reported consumption during the previous 12 months because questionnaire items differed by cycle. Physical activity was coded as any versus no reported activity. Survey cycle was included in the fully adjusted model to account for possible differences between 2015–2016 and 2017–2018.

2.6. Statistical analysis

All analyses accounted for the complex multistage sampling design of NHANES. The two 2-year MEC examination weights were combined by dividing each cycle-specific MEC weight by two to obtain a 4-year examination weight. Primary sampling units and sampling strata were incorporated in all survey-weighted estimates and regression models in accordance with NHANES analytic guidance [6]. Continuous characteristics were summarized using survey-weighted means, and categorical characteristics were summarized using survey-weighted proportions. Unweighted sample counts were also reported to describe the available analytic sample.

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Associations between BMI–WC phenotype and binary cardiometabolic outcomes were evaluated using survey-weighted logistic regression. Normal weight without central obesity was used as the reference phenotype. Three sequential models were fitted for the primary hypertension outcome. Model 1 was specified as:

$$\mathrm{logit}[\mathrm{P}(\mathrm{Y}=1)] = \beta_0 + \beta_1\mathrm{G2} + \beta_2\mathrm{G3} + \beta_3\mathrm{G4} \tag{1}$$

where Y represents the binary outcome and G2, G3, and G4 are indicator variables for the three BMI–WC phenotypes relative to G1.For the adjusted analyses, Models 2 and 3 were expressed using the general form:

$$\mathrm{logit}\left[\mathrm{P}\left(\mathrm{Y}=1\right)\right] = \beta_0 + \beta_1\mathrm{G2} + \beta_2\mathrm{G3} + \beta_3\mathrm{G4} + \gamma^{\mathrm{T}}\mathrm{X} \tag{2}$$

where X represents the vector of adjustment covariates and γ represents the corresponding regression coefficients. In Model 2, the covariate vector included age, sex, and race. Model 3, considered the primary fully adjusted model, additionally included educational attainment, family income-to-poverty ratio (PIR), smoking status, alcohol consumption, physical activity, and NHANES survey cycle. Exponentiation of β_1, β_2, and β_3 yielded the odds ratios for G2, G3, and G4, respectively, relative to G1.

An extended model was additionally adjusted for diabetes to assess whether the primary association was materially altered after accounting for diabetes status.

The primary contrast compared normal-weight central obesity with normal weight without central obesity. Additional pairwise comparisons contrasted normal-weight central obesity with each BMI-defined overweight/obesity phenotype. Benjamini–Hochberg false discovery rate-adjusted P values were additionally calculated across these three pairwise comparisons. Diabetes and low HDL-C were analyzed as secondary outcomes using the same three-model adjustment strategy. Effect modification by sex was explored by including a phenotype-by-sex interaction term in the fully adjusted model and evaluating the interaction using a survey-adjusted Wald test. Sex-stratified estimates were considered exploratory, and models were not fitted when phenotype-specific sample sizes or event counts were insufficient for stable estimation.

Two principal sensitivity analyses were conducted. First, the primary hypertension model was repeated using the alternative 140/90-mmHg definition. Second, central obesity was redefined based on a waist-to-height ratio (WHtR) ≥0.5, and the four BMI–adiposity phenotypes were reconstructed accordingly. Cycle-specific models were also examined as a supplementary assessment of consistency across NHANES 2015-2016 and 2017-2018.

Model adequacy was assessed by examining model convergence, phenotype-specific event and non-event counts. The overall contribution of the phenotype variable was evaluated using a global survey-adjusted Wald test. Multicollinearity among Model 3 predictors was assessed using generalized variance inflation factors (GVIFs) calculated from a conventional logistic regression that contained the same predictors and was restricted to the same complete-case sample; adjusted GVIF values, accounting for the degrees of freedom of categorical variables, were examined. All statistical tests were two-sided, and $P<0.05$ was considered statistically significant.

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3. Results

3.1. Study population and BMI–waist phenotype distribution

A total of 19,225 participants were available across the NHANES 2015-2016 and 2017-2018 cycles. After the sample was restricted to adults aged ≥18 years, 11,848 participants remained. Further exclusions were made for participants who did not complete the mobile examination center assessment, had confirmed pregnancy, lacked valid BMI or waist circumference measurements, had BMI <18.5 kg/m², lacked valid survey design variables, or had indeterminate hypertension status. The final analytic cohort comprised 9,867 adults (Figure 1).

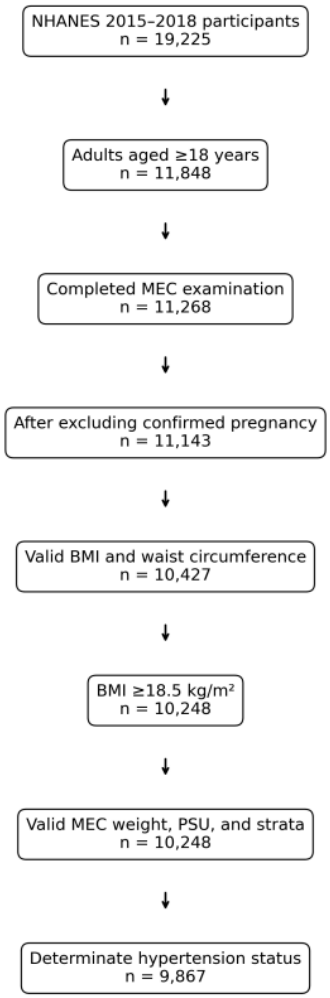

Figure 1. Flowchart of participant selection for the analytic cohort, NHANES 2015-2018

Of these, 2,410 participants were classified as normal weight without central obesity, 257 as having normal-weight central obesity (NWCO), 1,626 as BMI-defined overweight/obesity without central obesity, and 5,574 as BMI-defined overweight/obesity with central obesity. After application of NHANES examination weights, the corresponding population proportions were 24.2%, 3.0%,

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15.6%, and 57.1%, respectively. Thus, NWCO represented a relatively small but identifiable subgroup of the US adult population.

3.2. Participant characteristics across BMI–waist phenotypes

Participant characteristics differed across the four BMI–waist phenotypes (Table 1). Adults with NWCO were older on average than those in the reference group, with weighted mean ages of 55.6 and 42.6 years, respectively. The NWCO phenotype was also predominantly female, with women accounting for 96.4% of the weighted group compared with 51.1% in the reference phenotype. In contrast, the BMI-defined overweight/obesity without central obesity group was predominantly male, with women representing only 17.6% of the weighted population.

The weighted proportion of non-Hispanic White adults was highest in the NWCO group (76.9%), compared with 64.0% in the reference group, 52.5% in the BMI-defined overweight/obesity without central obesity group, and 65.7% in the BMI-defined overweight/obesity with central obesity group. The proportion with a college degree or higher was similar between the two normal-BMI phenotypes (39.3% in the reference group and 38.5% in NWCO), but lower in the BMI-defined overweight/obesity with central obesity group (27.4%).

Lifestyle and metabolic characteristics also varied across phenotypes. The weighted prevalence of any physical activity was lower in NWCO than in the reference group (74.0% vs 85.6%). Diabetes prevalence was 6.8% in NWCO compared with 4.1% in the reference group, whereas low HDL-C prevalence was present in 16.5% and 11.9%, respectively.

Table 1. Characteristics of participants according to BMI–waist circumference phenotype, NHANES 2015-2018

Characteristic	Normal weight without central obesity	Normal-weight central obesity	BMI overweight/obesity without central obesity	BMI overweight/obesity with central obesity
Unweighted n	2,410	257	1,626	5,574
Age, years	42.6 (0.5)	55.6 (1.1)	42.8 (0.6)	50.7 (0.4)
PIR	3.0 (0.1)	3.2 (0.2)	3.2 (0.1)	3.0 (0.1)
Sex, n (weighted %)				
Female	1141 (51.1)	247 (96.4)	284 (17.6)	3327 (57.2)
Male	1269 (48.9)	10 (3.6)	1342 (82.4)	2247 (42.8)
Race/ethnicity, n (weighted %)				

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Table 1. (continued)

Mexican American	232 (5.9)	23 (4.4)	289 (12.1)	1027 (9.9)
Other Hispanic	198 (5.2)	23 (3.1)	241 (11.4)	640 (5.8)
Non-Hispanic White	781 (64.0)	124 (76.9)	400 (52.5)	2010 (65.7)
Non-Hispanic Black	492 (10.7)	41 (6.0)	347 (11.9)	1311 (11.5)
Non-Hispanic Asian	598 (10.9)	37 (5.0)	287 (8.2)	330 (2.6)
Other/multiracial	109 (3.5)	9 (4.6)	62 (3.9)	256 (4.5)
Education, n (weighted %)				
Less than 9th grade	156 (3.5)	22 (3.3)	171 (5.9)	572 (4.7)
9-11th grade	269 (8.7)	27 (6.4)	178 (7.9)	603 (7.4)
High school/GED	472 (20.6)	64 (25.4)	338 (23.0)	1298 (26.0)
Some college/AA	581 (27.9)	75 (26.3)	409 (28.3)	1848 (34.5)
College graduate or above	702 (39.3)	68 (38.5)	440 (34.9)	1118 (27.4)
Smoking status, n (weighted %)				
Never	1517 (62.0)	161 (60.1)	947 (57.4)	3219 (55.6)
Former	393 (17.5)	48 (21.9)	370 (24.8)	1433 (28.4)
Current	498 (20.5)	48 (18.0)	308 (17.8)	917 (16.0)
Alcohol use in past 12 months, n (weighted %)				
Yes	1554 (77.1)	137 (70.7)	1120 (78.1)	3465 (73.4)
No	696 (22.9)	96 (29.3)	435 (21.9)	1802 (26.6)
Physical activity, n (weighted %)				

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Table 1. (continued)

Any reported activity	1929 (85.6)	158 (74.0)	1345 (86.7)	3985 (76.0)
No reported activity	481 (14.4)	99 (26.0)	281 (13.3)	1589 (24.0)
Cardiometabolic profile, n (weighted %)				
Hypertension	28.7	48.0	39.8	58.9
Diabetes	170 (4.1)	32 (6.8)	162 (6.9)	1212 (16.9)
Low HDL-C	314 (11.9)	46 (16.5)	404 (22.9)	2112 (37.6)

Notes: Continuous variables are presented as survey-weighted mean (standard error). Categorical variables are presented as unweighted number (survey-weighted percentage), unless otherwise indicated. Hypertension prevalence is presented as survey-weighted prevalence (%).

3.3. Hypertension prevalence across BMI–waist phenotypes

Survey-weighted hypertension prevalence differed across BMI–waist phenotypes (Figure 2). The reference group had the lowest prevalence, at 28.7%. In contrast, hypertension prevalence was 48.0% among adults with NWCO, 39.8% among those with BMI-defined overweight/obesity without central obesity, and 58.9% among those with both elevated BMI and central obesity.

The descriptive pattern therefore showed substantially higher hypertension prevalence among adults with NWCO than among those with both normal BMI and normal waist circumference. However, because the phenotype groups also differed in age, sex, and other characteristics, adjusted regression analyses were subsequently performed to evaluate whether these differences persisted after accounting for potential confounding factors.

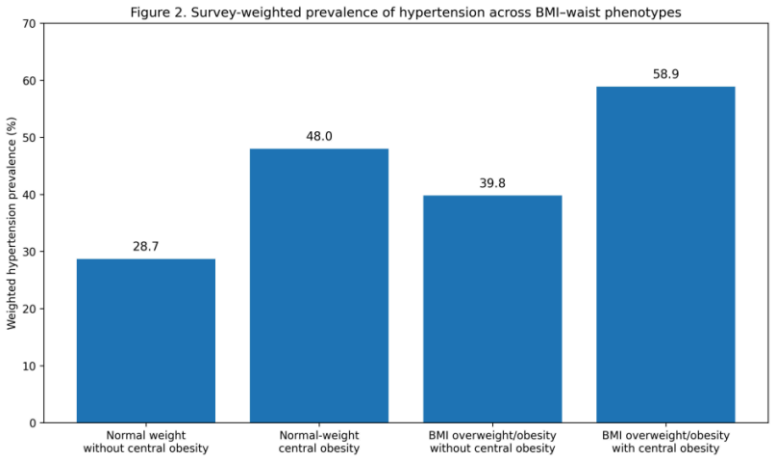

Figure 2. Survey-weighted prevalence of hypertension across BMI–waist circumference phenotypes, NHANES 2015-2018

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3.4. Association between BMI–waist circumference phenotype and hypertension

Table 2 summarizes the associations between BMI–WC phenotype and hypertension across the sequential models. For participants with normal-weight central obesity, the OR decreased from 2.29 (95% CI 1.50–3.51) in Model 1 to 1.83 (95% CI 1.07–3.12) in Model 2. After full covariate adjustment in Model 3, the estimate was 2.12 (95% CI 1.13–4.00; P=0.024). Adding diabetes to the model had little influence on this result (OR 2.13, 95% CI 1.14–3.98).

In Model 3, the OR for overweight/obesity without central obesity was 1.61 (95% CI 1.17–2.20; P=0.007), whereas the group with both elevated BMI and central obesity showed the largest estimate (OR 3.23, 95% CI 2.55–4.09; P<0.001). Overall, the NWCO estimate remained above 1 across all levels of adjustment.

Table 2. Association between BMI–waist circumference phenotype and prevalent hypertension, NHANES 2015-2018

Phenotype	Model 1	Model 2	Model 3	Extended model
Normal weight without central obesity	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Normal-weight central obesity	2.29 (1.50-3.51)	1.83 (1.07-3.12)	2.12 (1.13-4.00)	2.13 (1.14-3.98)
BMI overweight/obesity without central obesity	1.64 (1.34-2.02)	1.50 (1.17-1.94)	1.61 (1.17-2.20)	1.59 (1.15-2.19)
BMI overweight/obesity with central obesity	3.56 (3.00-4.21)	3.22 (2.62-3.96)	3.23 (2.55-4.09)	3.02 (2.36-3.87)

3.5. Pairwise comparisons centered on normal-weight central obesity

Pairwise contrasts were used to place the NWCO group directly against each of the other BMI–WC phenotypes. Relative to the normal-weight, non-central-obesity group, NWCO showed higher odds of hypertension (OR 2.12, 95% CI 1.13–4.00; P=0.024). The estimate for NWCO versus overweight/obesity without central obesity was 1.32 (95% CI 0.68–2.56; P=0.369), while the corresponding estimate versus overweight/obesity with central obesity was 0.66 (95% CI 0.38–1.15; P=0.128).

The latter two contrasts were imprecise and did not reach statistical significance. These findings should not be taken to indicate equivalence between NWCO and either overweight/obesity phenotype.

After Benjamini–Hochberg adjustment across the three NWCO-centered comparisons, the adjusted P value for the NWCO versus reference-group contrast was 0.072. Because this comparison was specified a priori as the primary contrast, the unadjusted result remained the primary inferential estimate, whereas the multiplicity-adjusted comparisons were treated as supplementary analyses.

3.6. Secondary cardiometabolic outcomes

Table 3 presents the fully adjusted estimates for the two secondary outcomes. For low HDL-C, the OR for NWCO relative to the reference phenotype was 1.96 (95% CI 1.22–3.16; P=0.011). The

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corresponding estimates were 2.55 (95% CI 1.94–3.35; P<0.001) for overweight/obesity without central obesity and 5.32 (95% CI 4.10–6.89; P<0.001) for overweight/obesity with central obesity.

A different pattern was observed for diabetes. The estimate for NWCO was 1.40 (95% CI 0.65–3.03; P=0.349) and did not reach statistical significance. In comparison, the ORs were 1.62 (95% CI 1.06–2.45; P=0.028) for overweight/obesity without central obesity and 4.43 (95% CI 3.00–6.55; P<0.001) for overweight/obesity with central obesity. Thus, the secondary analyses provided stronger evidence for an association between NWCO and low HDL-C than for diabetes.

Table 3. Fully adjusted associations between BMI–waist circumference phenotype and secondary cardiometabolic outcomes

Outcome / phenotype	OR (95% CI)	P value
Diabetes		
Normal weight without central obesity	1.00 (Reference)	—
Normal-weight central obesity	1.40 (0.65-3.03)	0.349
BMI overweight/obesity without central obesity	1.62 (1.06-2.45)	0.028
BMI overweight/obesity with central obesity	4.43 (3.00-6.55)	<0.001
Low HDL-C		
Normal weight without central obesity	1.00 (Reference)	—
Normal-weight central obesity	1.96 (1.22-3.16)	0.011
BMI overweight/obesity without central obesity	2.55 (1.94-3.35)	<0.001
BMI overweight/obesity with central obesity	5.32 (4.10-6.89)	<0.001

3.7. Sensitivity and additional analyses

The primary hypertension findings were robust to alternative outcome and exposure definitions (Table 4). Using the 140/90-mmHg hypertension criterion, the OR for NWCO versus the reference phenotype was 2.37 (95% CI 1.27–4.40; P=0.011). When central obesity was instead defined by WHtR ≥0.5, the corresponding estimate was 1.72 (95% CI 1.15–2.58; P=0.014). Thus, both alternative specifications produced results in the same direction as the primary analysis.

The phenotype-by-sex interaction was not significant (P=0.791). Interpretation of sex-specific estimates was nevertheless limited by the small number of men with NWCO. Only seven men in the fully adjusted complete-case sample belonged to this phenotype, which was insufficient for stable male-specific estimation. Sex-stratified findings were therefore treated as exploratory.

Table 4. Sensitivity analyses for prevalent hypertension

Analysis	G2 vs G1	G3 vs G1	G4 vs G1
Primary: hypertension ≥130/80; WC ≥102/88 cm	2.12 (1.13-4.00)	1.61 (1.17-2.20)	3.23 (2.55-4.09)
Hypertension ≥140/90 mmHg	2.37 (1.27-4.40)	1.82 (1.28-2.59)	3.80 (2.97-4.85)

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Table 4. (continued)

Central obesity: WHtR ≥0.5	1.72 (1.15-2.58)	2.56 (1.05-6.23)	3.37 (2.35-4.82)

3.8. Model diagnostics

All primary survey-weighted logistic regression models converged successfully. Within the fully adjusted Model 3 sample, the normal-weight central obesity group included 204 participants, of whom 119 had hypertension and 85 did not. This pattern indicates adequate outcome variation within the primary exposure group.

The BMI–WC phenotype variable was significantly associated with hypertension as an overall model term. In Model 3, the global survey-adjusted Wald test yielded F=61.73 with P<0.001. Multicollinearity diagnostics showed no evidence of problematic collinearity among the fully adjusted model predictors; adjusted GVIF values were all close to 1, with the highest value approximately 1.19.

Taken together, the convergence results, event structure, global Wald test, and multicollinearity diagnostics supported the stability of the primary fully adjusted model.

Table 5. Model diagnostics and multicollinearity assessment

Multicollinearity diagnostics				
variable	GVIF	Df	adjusted_GVIF	
phenotype_code	1.340195695	3	1.050013065	
age	1.187508284	1	1.089728537	
sex	1.239117199	1	1.113156413	
race_ethnicity	1.598819751	5	1.048045048	
education	1.735445732	4	1.07133768	
PIR	1.406571533	1	1.185989685	
smoking_status	1.266184098	2	1.060777291	
alcohol_current	1.137136763	1	1.066366148	
physical_activity	1.073027907	1	1.035870603	
cycle	1.021544416	1	1.010714805	
Global Wald tests				
model	F_statistic	numerator_df	denominator_df	p_value
Model 1	132.3326396	3	27	2E-16
Model 2	86.05138695	3	20	1.32123E-11
Model 3	61.72803358	3	10	9.3496E-07

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4. Conclusion

The results from NHANES 2015–2018 show that a normal BMI does not always correspond to a well-performed cardiometabolic profile. Participants with normal-weight and central obesity had higher odds of hypertension than those with both normal BMI and normal waist circumference, even after adjustment for major demographic and lifestyle factors. This group also showed higher odds of low HDL-C, while the association with diabetes was not statistically significant.

These findings support the idea that BMI and waist circumference provide different information about adiposity. In practice, relying on BMI alone may miss some adults who have excess abdominal fat despite being classified as normal weight. Waist circumference may therefore be useful as an additional measure when evaluating cardiometabolic health.

Because this study was cross-sectional, the results describe associations rather than causation. Further longitudinal research is needed to examine whether these phenotype differences are also related to future hypertension and cardiovascular events.

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