Body Mass Index, Waist Circumference, and Impaired Fasting Glucose in a Defined NHANES 2021–2023 Adult Fasting Subpopulation

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Received June 28, 2026
Accepted October 6, 2026
Electronic access November 30, 2026

Background: Body mass index (BMI) is widely used to characterize adiposity but does not directly capture central body size. We examined associations of BMI, waist circumference (WC), and combined BMI-WC phenotypes with impaired fasting glucose (IFG) in a defined NHANES 2021–2023 adult fasting subpopulation.
Methods: The survey design was constructed among participants with positive fasting-subsample weights before analytic restrictions were applied by domain analysis. Adults aged $\geq$18 years with measured fasting plasma glucose (FPG), BMI, and WC were eligible after excluding pregnancy, diagnosed diabetes or glucose-lowering treatment, and FPG $\geq$126 mg/dL. IFG was defined as FPG 100–125 mg/dL.
Results: The primary analytic sample included 2,393 adults; fully adjusted models included 2,366. Survey-weighted IFG prevalence was 44.0% (95% CI 40.8%–47.1%) in the defined analytic subpopulation. In separate fully adjusted models, BMI (OR 1.060 per 1 kg/m^2, 95% CI 1.042–1.078) and WC (OR 1.029 per 1 cm, 95% CI 1.022–1.036) were associated with higher IFG odds. In the mutually adjusted model, BMI was not statistically significant (OR 0.973, 95% CI 0.915–1.035; $P = 0.357$), whereas WC remained associated with IFG (OR 1.041, 95% CI 1.015–1.068; $P = 0.004$). BMI $\geq$25 kg/m^2 with elevated WC was associated with higher IFG odds than BMI $<$25 kg/m^2 with non-elevated WC (OR 2.802, 95% CI 2.155–3.644).
Conclusions: BMI and WC were each associated with prevalent IFG in this analytic subpopulation. The mutually adjusted coefficients are conditional associations and do not establish statistical or predictive superiority of WC over BMI.

Keywords: impaired fasting glucose; body mass index; waist circumference; central adiposity; NHANES; complex survey.

Introduction

Impaired fasting glucose (IFG) is an early dysglycemic state associated with subsequent type 2 diabetes and cardiometabolic morbidity. Current diagnostic guidance defines IFG as fasting plasma glucose (FPG) 100–125 mg/dL, while diabetes-range FPG begins at 126 mg/dL[1]. Longitudinal U.S. data show that baseline FPG, age, sex, and BMI jointly shape progression to diabetes, and other contemporary cohorts similarly identify substantial heterogeneity in progression from prediabetes[2,3].

Body mass index (BMI) remains a practical measure of general adiposity, but it cannot distinguish fat from lean mass or describe fat distribution. In the Fasa Adults Cohort Study, BMI showed a nonlinear association with fasting blood glucose[4]. In a prospective Chinese cohort, baseline WC and changes in WC were associated with incident type 2 diabetes, with stronger associations for WC than BMI in that population[5]. U.S. longitudinal data linked BMI and WC measured in young adulthood with later incident diabetes[6]. A Japanese longitudinal study found that both BMI and WC predicted incident diabetes, with sex-specific differences in comparative performance[7]. In UK Biobank, waist-to-height ratio showed stronger association and discrimination for incident type 2 diabetes than several other anthropometric measures[8]. Dutch cohort data similarly found relative fat mass more strongly associated with incident diabetes than traditional indices[9]. Whitehall II data linked 10-year changes in WC and waist-to-height ratio more strongly with diabetes than BMI change[10]. Repeated fluctuations in WC were also associated with diabetes incidence in a large older-adult Chinese cohort[11]. Waist circumference (WC) is a simple marker of central body size and is frequently used alongside BMI. A prospective Chinese data-linkage study reported independent and joint associations of BMI and WC with incident type 2 diabetes[12]. Cross-sectional multiethnic data also showed that combined BMI-WC categories were associated with metabolic syndrome components[13]. Normal-weight central obesity has been associated with diabetes, indicating that discordance between BMI and WC can identify metabolically distinct subgroups[14]. Recent research has broadened the set of anthropometric measures

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examined in dysglycemia. A contemporary NHANES 2021–2023 analysis compared multiple anthropometric indices for prevalent prediabetes[15]. Earlier NHANES analyses linked body roundness index[16] and visceral adiposity index[17] with diabetes or prediabetes prevalence. Fat-mass and fat-free-mass indices[18] and visceral adiposity index/lipid accumulation product[19] have also been examined in relation to dysglycemia. Weight-adjusted waist index has been compared with BMI and WC in NHANES[20] and evaluated in a separate U.S. adult analysis[21]. Prospective work has assessed weight-adjusted waist index for diabetes and related outcomes[22], while waist-corrected BMI has been associated with incident diabetes[23]. Among adults with prediabetes, long-term cohort data have compared novel anthropometric indices for progression to diabetes[24], and cross-sectional case-control work has examined several novel measures[25]. Repeated-measure cohort analysis has evaluated whether longitudinal anthropometric and body-composition measures improve incident diabetes prediction[26]. Anthropometric indices have additionally been related to cardiovascular disease prevalence among NHANES adults with prediabetes or diabetes[27]. Together, these studies broaden the evidence base but do not support a single universally superior anthropometric measure because populations, outcomes, model structures, and performance metrics differ. Foundational epidemiologic and clinical studies likewise support considering WC as complementary to BMI[28,29].

A recent NHANES 2021–2023 analysis compared multiple anthropometric indices for prediabetes, emphasizing the continuing interest in contemporary U.S. data[15]. However, an IFG-focused analysis of the fasting subsample can address a more specific question by using the fasting laboratory weight, defining a clear glycemic subpopulation, and examining BMI and WC both separately and jointly. Because BMI and WC are correlated, coefficients from a mutually adjusted model are interpreted as conditional associations rather than as a direct test of predictive superiority. Accordingly, this study used NHANES August 2021–August 2023 data to examine: (1) the association of BMI with prevalent IFG; (2) the association of WC with prevalent IFG; (3) the conditional associations of BMI and WC when entered simultaneously; and (4) associations of combined BMI-WC phenotypes with prevalent IFG. HbA1c-defined prediabetes and alternative covariate specifications were evaluated as sensitivity analyses.

Methods

Study Design and Data Source

This cross-sectional study used publicly available NHANES August 2021–August 2023 data[30]. The analytic dataset linked demographic, body measures, fasting glucose, glycohemoglobin, diabetes questionnaire, smoking questionnaire, and physical activity files by respondent sequence number (SEQN). The fasting glucose file supplied WTSAF2YR, the appropriate fasting-subsample weight[31]. NHANES uses a stratified, multistage probability design to sample the U.S. civilian noninstitutionalized population and releases masked strata and primary sampling unit variables for variance estimation[32].

Study Population

The fasting glucose file contained 3,996 records. The survey design was first constructed among all 3,361 participants with WTSAF2YR > 0; eligibility restrictions were then applied to the survey object as a domain. NCHS assigns WTSAF2YR$= 0$ to participants without a fasting laboratory result or to those who did not meet the required 8 to $<$24-hour fasting duration[31]. The analytic domain required age $\geq$18 years and nonmissing FPG, BMI, WC, age, sex, and race/ethnicity, and excluded pregnancy, diagnosed diabetes or current glucose-lowering treatment, and FPG $\geq$126 mg/dL. Figure 1 reports exclusions in the same order as the analytic workflow: WTSAF2YR$= 0$ ($n = 635$); age $<$18 years ($n = 298$); missing FPG ($n = 0$ among positive-weight adults); missing BMI ($n = 37$); missing WC ($n = 98$); missing age, sex, or race/ethnicity ($n = 0$); pregnancy ($n = 15$); diagnosed diabetes or glucose-lowering treatment ($n = 416$); and FPG $\geq$126 mg/dL ($n = 104$). The final primary analytic sample comprised 2,393 adults.

Among the 2,393 participants in the primary analytic domain, smoking status was missing for 4 and physical activity for 25; because of overlap, 27 participants lacked at least one of these covariates. Fully adjusted complete-case models therefore included 2,366 participants. Education was missing for 99 participants and poverty-income ratio (PIR) for 279; extended models containing all primary and socioeconomic covariates included 2,005 participants.

Outcome Definition

The primary outcome was prevalent IFG, defined as FPG 100–125 mg/dL. Participants with FPG $<$100 mg/dL formed the reference group, while participants with FPG $\geq$126 mg/dL were excluded from the primary analytic domain[1].

For the HbA1c sensitivity analysis, we started from the primary analytic domain and retained participants with nonmissing HbA1c $<$6.5%. HbA1c 5.7%–6.4% was classified as prediabetes and HbA1c $<$5.7% as the reference category[1]. Participants with HbA1c $\geq$6.5% were excluded from this binary sensitivity analysis. This produced 2,365 participants with 609 HbA1c-prediabetes cases; 2,339 participants (601 cases) had complete primary adjustment covariates.

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Anthropometric Exposures

BMI was taken from the NHANES body measures file and analyzed continuously per 1 kg/m^2 and categorically as $<$25.0, 25.0–29.9, and $\geq$30.0 kg/m^2. WC was analyzed continuously per 1 cm and categorically as elevated versus non-elevated. Elevated WC was defined as $>$102 cm in men and $>$88 cm in women, consistent with conventional clinical thresholds used in prior BMI-WC research[28,29].

For joint phenotypes, participants were classified as BMI $<$25 kg/m^2 with non-elevated WC; BMI $<$25 kg/m^2 with elevated WC; BMI $\geq$25 kg/m^2 with non-elevated WC; or BMI $\geq$25 kg/m^2 with elevated WC. BMI $<$25 kg/m^2 with non-elevated WC served as the reference category.

Covariates and Variable Coding

Primary adjustment covariates were selected a priori and included age, sex, race/ethnicity, cigarette smoking status, and leisure-time physical activity. Age was modeled as a continuous linear term in the primary models. Smoking status was coded as never, former, or current from SMQ020 and SMQ040. Leisure-time activity used PAD790Q/PAD790U/PAD800 for moderate activity and PAD810Q/PAD810U/PAD820 for vigorous activity. Reported frequencies were converted to weekly frequency according to the recorded day/week/month/year unit; moderate-equivalent minutes per week were calculated as moderate minutes plus twice vigorous minutes. Participants were classified as meeting $\geq$150 moderate-equivalent minutes per week versus $<$150 minutes per week.

The extended socioeconomic models additionally included education and PIR. Education was categorized as less than high school, high school/GED, or more than high school. To avoid imposing a linear functional form on PIR, it was categorized as $<$1.30, 1.30–3.49, or $\geq$3.50. Refused, do-not-know, and missing responses were treated as missing; structurally skipped activity-duration items were assigned zero minutes only when the corresponding activity frequency was zero. Exact NHANES files, variables, and coding rules are provided in Supplementary Table S1.

Statistical analysis

Analyses were performed in R 4.5.0 using the survey package version 4.5[33]. The survey design object was constructed before analytic exclusions among all fasting-file participants with WTSAF2YR $>$ 0 using `svydesign(ids=~SDMVPSU, strata=~SDMVSTRA, weights=~WTSAF2YR, nest=TRUE)`. Analytic restrictions were then applied with `subset()` to preserve the full complex-survey design for domain estimation. The source design contained 15 masked strata and 30 masked primary sampling units (PSUs); each stratum contained two PSUs. The option `survey.lonely.psu='adjust'` was specified for reproducibility, although no lonely PSU occurred in the positive-weight source design. This procedure follows NHANES guidance to use the released sampling weights, strata, and PSU variables for variance estimation[31,32].

Survey-weighted means and proportions were used to summarize participant characteristics. Design-based tests compared characteristics by FPG status. Survey-weighted logistic regression estimated prevalence odds ratios (ORs) and 95% confidence intervals (CIs) for IFG. Model 1 was unadjusted; Model 2 adjusted for age, sex, and race/ethnicity; Model 3 additionally adjusted for smoking and physical activity. BMI and WC were first examined separately and then simultaneously. Because the outcome is prevalent IFG in a cross-sectional study, ORs are interpreted as prevalence odds rather than prospective risk estimates.

The mutually adjusted model was interpreted as estimating conditional associations of BMI and WC. We did not use the difference in coefficient significance to infer statistical or predictive superiority, and the study did not evaluate discrimination, calibration, sensitivity, specificity, or prospective prediction.

Restricted spline models were refitted using the same survey-domain design to visualize adjusted exposure-response patterns for BMI and WC. Sensitivity analyses used HbA1c-defined prediabetes as the outcome, including separate BMI and WC models, a mutually adjusted model, and extended socioeconomic adjustment. To evaluate the functional form of age, primary IFG models were repeated with age categorized as 18–39, 40–59, and $\geq$60 years. Two-sided $P < 0.05$ was considered statistically significant.

Ethical considerations

NHANES data are publicly available and de-identified. NHANES protocols are approved by the NCHS Ethics Review Board and participants provide consent as part of the survey[30]. This secondary analysis of public de-identified data did not require additional institutional ethics approval or participant re-consent.

Results

Participant selection and prevalence of IFG

Among 3,996 participants in the fasting glucose file, sequential restrictions yielded a final primary analytic domain of 2,393 adults (Figure 1). The survey-weighted prevalence of IFG was 44.0% (95% CI 40.8%–47.1%) among the defined analytic subpopulation of U.S. civilian noninstitutionalized adults meeting the study eligibility criteria. This estimate

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should not be interpreted as the prevalence of IFG among all U.S. adults. Fully adjusted models included 2,366 participants with complete smoking and physical-activity data.

Participant characteristics

Participants with IFG were older and had higher mean BMI and WC than participants with normal FPG. The IFG group also had a higher weighted proportion of elevated WC and a higher proportion with BMI $\geq$30 kg/m^2. Weighted distributions of sex, race/ethnicity, smoking status, and physical activity are shown in Table 1.

Associations of BMI and waist circumference with IFG

BMI was positively associated with prevalent IFG when analyzed separately. In Model 3, each 1 kg/m^2 higher BMI was associated with higher IFG odds (OR 1.060, 95% CI 1.042–1.078, $P < 0.001$). Relative to BMI <25 kg/m^2, the adjusted ORs were 1.683 (95% CI 1.285–2.204, $P < 0.001$) for BMI 25.0–29.9 kg/m^2 and 2.578 (95% CI 2.025–3.284, $P < 0.001$) for BMI $\geq$30 kg/m^2 (Table 2).

WC was also associated with prevalent IFG when analyzed separately. Each 1 cm higher WC was associated with higher IFG odds in Model 3 (OR 1.029, 95% CI 1.022–1.036, $P < 0.001$), and elevated WC versus non-elevated WC had an OR of 2.567 (95% CI 1.977–3.333, $P < 0.001$) (Table 2). Survey-domain spline refits showed broadly increasing adjusted IFG odds across higher BMI and WC values (Figure 2A–**??**).

Mutually adjusted BMI-WC model

When BMI and WC were included simultaneously with the Model 3 covariates, BMI was not statistically significant (OR 0.973, 95% CI 0.915–1.035, $P = 0.357$), whereas WC remained associated with prevalent IFG (OR 1.041 per 1 cm, 95% CI 1.015–1.068, $P = 0.004$) (Table 2). Because BMI and WC are correlated, these coefficients represent conditional associations and do not demonstrate statistical or predictive superiority of one anthropometric measure over the other.

BMI-WC phenotype analysis

Compared with BMI <25 kg/m^2 plus non-elevated WC, BMI $\geq$25 kg/m^2 plus elevated WC was associated with higher prevalent IFG odds (OR 2.802, 95% CI 2.155–3.644, $P < 0.001$) (Table 3 and Figure 3). BMI <25 kg/m^2 plus elevated WC had a higher point estimate but a wide CI (OR 2.321, 95% CI 0.756–7.123, $P = 0.130$; $n = 60$), while BMI $\geq$25 kg/m^2 plus non-elevated WC was not statistically significant (OR 1.246, 95% CI 0.913–1.700, $P = 0.153$).

Sensitivity and robustness analyses

The HbA1c sensitivity domain contained 2,365 participants with HbA1c <6.5%, including 609 with HbA1c 5.7%–6.4%. Fully adjusted complete-case models included 2,339 participants and 601 cases. When modeled separately, BMI (OR 1.069 per 1 kg/m^2, 95% CI 1.051–1.088, $P < 0.001$) and WC (OR 1.031 per 1 cm, 95% CI 1.022–1.039, $P < 0.001$) were associated with HbA1c-defined prediabetes. In the mutually adjusted model, BMI was OR 1.025 (95% CI 0.972–1.080, $P = 0.346$) and WC was OR 1.020 (95% CI 0.997–1.045, $P = 0.088$). Extended socioeconomic results are reported in Supplementary Table S3.

Replacing linear age with age categories produced similar main IFG estimates: BMI OR 1.062 (95% CI 1.045–1.080) and WC OR 1.030 (95% CI 1.023–1.037) when modeled separately; in the mutually adjusted model, BMI OR 0.968 (95% CI 0.909–1.032, $P = 0.297$) and WC OR 1.044 (95% CI 1.016–1.072, $P = 0.004$). In extended IFG models containing education and categorical PIR ($n = 2{,}005$), BMI and WC remained associated when modeled separately, while the mutually adjusted estimates were BMI OR 0.967 (95% CI 0.908–1.030, $P = 0.277$) and WC OR 1.042 (95% CI 1.016–1.069, $P = 0.003$) (Supplementary Table S4).

Discussion

In this survey-weighted cross-sectional analysis, both BMI and WC were associated with prevalent IFG when considered separately in the defined NHANES 2021–2023 adult fasting subpopulation. In the mutually adjusted model, the WC term remained statistically significant while the BMI term did not. This result describes conditional associations within a model containing two correlated anthropometric measures; it does not establish that WC is statistically or predictively superior to BMI. The combined BMI-WC analysis additionally showed that participants with both BMI $\geq$25 kg/m^2 and elevated WC had higher prevalent IFG odds than the reference phenotype.

Recent studies focused specifically on prediabetes or IFG provide useful context. In the Aichi Workers' Cohort, increases in BMI and WC were each associated with incident prediabetes[34]. A Chinese cross-sectional study reported positive associations of BMI and WC with prevalent prediabetes[35]. In a community cohort of adults with prediabetes, changes in BMI and body fat percentage, but not WC, were associated with remission and progression over 2.5 years[36]. In the PURE Poland cohort of adults with IFG, BMI, WC, and waist-to-height ratio showed similar long-term predictive performance for diabetes[37]. These differing results support a cautious interpretation rather than a universal ranking of BMI and WC. Broader longitudinal evidence has linked young-adult BMI and WC with later diabetes[6]. Changes in WC

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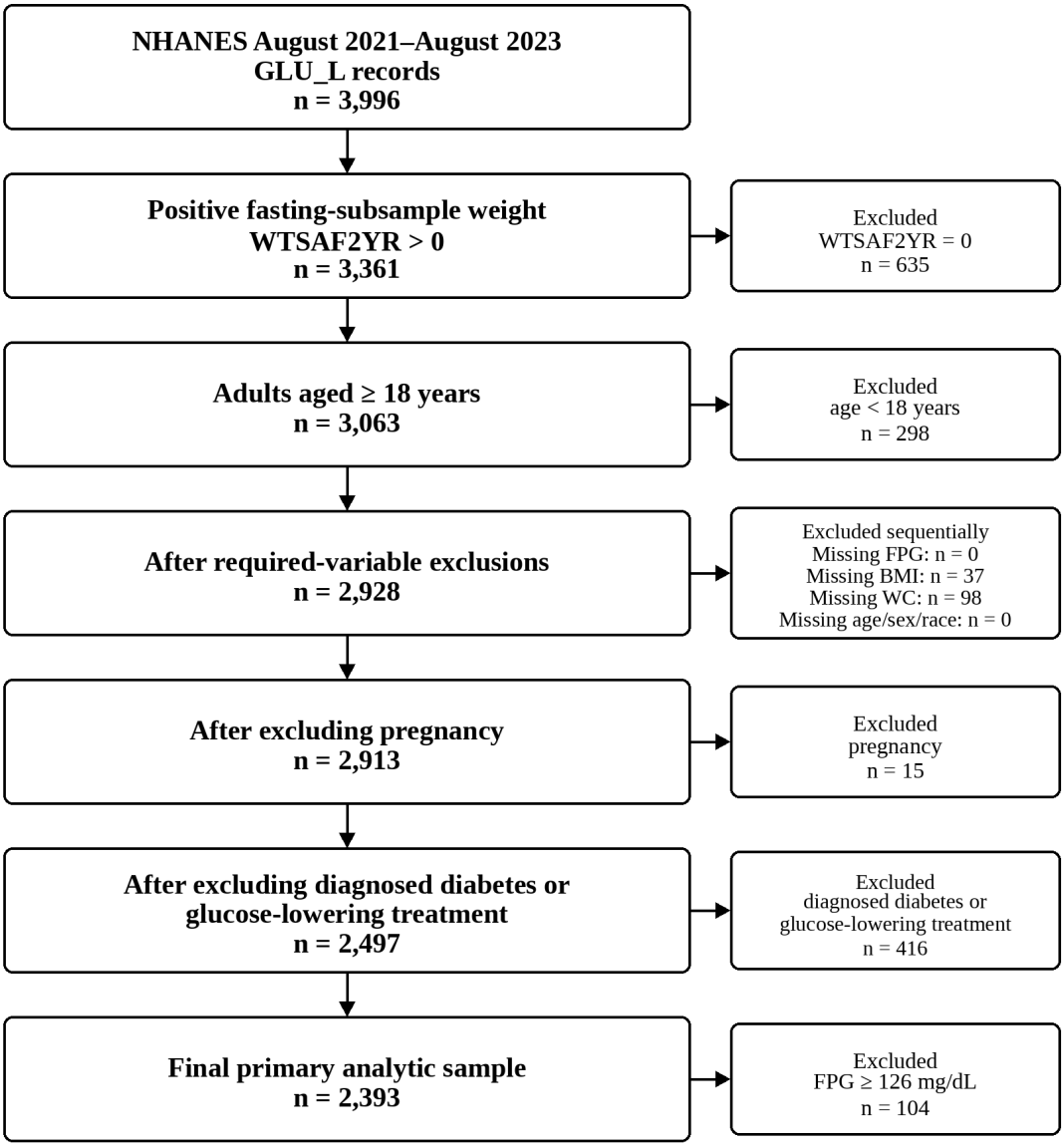

WTSAF2YR = 0 comprises participants without a fasting laboratory result or who did not meet the required fasting duration.
Model-specific missingness after the primary analytic sample: smoking n = 4; physical activity n = 25; smoking or physical activity n
education n = 99; poverty-income ratio n = 279.

Figure. 1 Participant selection flowchart. BMI, body mass index; FPG, fasting plasma glucose; NHANES, National Health and Nutrition Examination Survey; WC, waist circumference; WTSAF2YR, fasting subsample 2-year examination weight.

have also been associated with incident diabetes in Chinese and British cohorts[5,10], while repeated WC fluctuation was associated with diabetes in older Chinese adults[11]. Comparative cohort studies have reported different leading measures: the Japanese study found sex-specific differences between BMI and WC[7]; UK Biobank favored waist-to-height ratio for discrimination[8]; and Dutch cohorts found relative fat mass more strongly associated with incident diabetes than traditional indices[9].

Contemporary cross-sectional NHANES studies have linked body roundness index[16] and visceral adiposity index[17] with diabetes or prediabetes prevalence. Fat-mass indices[18] and visceral adiposity index/lipid accumulation product[19] have also been examined in relation to dysglycemia.

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Table 1 Participant characteristics according to fasting plasma glucose status.

Characteristic	Overall	Normal FPG	IFG	P value
Age, years	45.7 ± 0.7	41.9 ± 0.7	50.6 ± 0.8	<0.001
BMI, kg/m^2	28.9 ± 0.3	27.8 ± 0.3	30.2 ± 0.3	<0.001
Waist circumference, cm	97.9 ± 0.7	94.1 ± 0.8	102.6 ± 0.7	<0.001
Sex				<0.001
Male	49.2% ± 1.1%	43.1% ± 1.8%	57.1% ± 1.8%	
Female	50.8% ± 1.1%	56.9% ± 1.8%	42.9% ± 1.8%	
Race/ethnicity				0.026
Mexican American	7.4% ± 1.9%	5.7% ± 1.6%	9.7% ± 2.5%	
Other Hispanic	9.4% ± 1.7%	9.9% ± 1.8%	8.9% ± 1.7%	
Non-Hispanic White	61.0% ± 2.3%	60.4% ± 2.6%	61.7% ± 2.7%	
Non-Hispanic Black	9.9% ± 1.3%	10.8% ± 1.6%	8.7% ± 1.3%	
Non-Hispanic Asian	6.3% ± 1.6%	6.7% ± 2.0%	5.8% ± 1.3%	
Other/Multi-racial	6.0% ± 0.6%	6.6% ± 0.7%	5.2% ± 0.9%	
BMI category				<0.001
<25	32.0% ± 2.1%	39.7% ± 2.4%	22.2% ± 2.0%	
25–29.9	32.0% ± 0.8%	30.8% ± 1.2%	33.6% ± 1.3%	
≥30	36.0% ± 1.8%	29.5% ± 2.2%	44.2% ± 1.8%	
Waist circumference status				<0.001
Not elevated	48.5% ± 1.8%	58.0% ± 2.3%	36.5% ± 2.0%	
Elevated	51.5% ± 1.8%	42.0% ± 2.3%	63.5% ± 2.0%	
Smoking status				0.019
Never	66.8% ± 1.9%	70.0% ± 2.2%	62.8% ± 2.5%	
Former	21.4% ± 1.0%	19.2% ± 1.1%	24.3% ± 1.5%	
Current	11.7% ± 1.4%	10.8% ± 1.6%	12.9% ± 2.0%	
Physical activity				<0.001
≥150 min/wk equivalent	58.5% ± 1.6%	61.5% ± 1.5%	54.7% ± 1.9%	
<150 min/wk equivalent	41.5% ± 1.6%	38.5% ± 1.5%	45.3% ± 1.9%	

Note. Continuous variables are survey-weighted mean ± standard error; categorical variables are survey-weighted percentage ± standard error. P values are design-based weighted comparisons. BMI, body mass index; FPG, fasting plasma glucose; IFG, impaired fasting glucose; WC, waist circumference.

Weight-adjusted waist index has been associated with diabetes in separate NHANES analyses[20,21]. The recent NHANES 2021–2023 comparison of multiple anthropometric indices reported differences in both association magnitude and discrimination for prediabetes[15]. The present analysis differs by focusing specifically on fasting-defined IFG within the fasting-subsample design and by explicitly distinguishing separate from mutually adjusted BMI and WC associations.

The mutually adjusted findings require cautious interpretation. BMI and WC are correlated measures of body size and adiposity, so each coefficient in a joint model estimates an association conditional on the other measure. A significant WC coefficient and a non-significant BMI coefficient are not themselves evidence that their effects differ significantly, nor do they demonstrate improved discrimination or screening performance. The study did not assess C-statistics, calibration, sensitivity, specificity, net reclassification, or prospective prediction. Studies that formally compare predictive performance use dedicated metrics and have reported heterogeneous results[7,8]. The phenotype analysis provides a complementary descriptive perspective. The highest IFG odds occurred in the group with BMI ≥25 kg/m^2 and elevated WC. The normal-BMI elevated-WC subgroup was small ($n = 60$), producing a wide confidence interval despite an elevated point estimate. Previous work on normal-weight central obesity suggests that discordant BMI and WC phenotypes can identify metaboli-

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Table 2 Survey-weighted logistic regression associations of BMI and waist circumference with prevalent IFG.

Exposure or contrast	Model n	OR (95% CI)	P value
BMI per 1 kg/m^2, Model 1 unadjusted	2,393	1.053 (1.037–1.070)	<0.001
BMI per 1 kg/m^2, Model 2 age/sex/race adjusted	2,393	1.061 (1.045–1.077)	<0.001
BMI per 1 kg/m^2, Model 3 fully adjusted	2,366	1.060 (1.042–1.078)	<0.001
BMI 25–29.9 vs <25, fully adjusted	2,366	1.683 (1.285–2.204)	<0.001
BMI ≥30 vs <25, fully adjusted	2,366	2.578 (2.025–3.284)	<0.001
Waist per 1 cm, Model 1 unadjusted	2,393	1.034 (1.027–1.042)	<0.001
Waist per 1 cm, Model 2 age/sex/race adjusted	2,393	1.030 (1.023–1.036)	<0.001
Waist per 1 cm, Model 3 fully adjusted	2,366	1.029 (1.022–1.036)	<0.001
Elevated waist circumference vs not elevated, fully adjusted	2,366	2.567 (1.977–3.333)	<0.001
BMI per 1 kg/m^2, mutually adjusted for WC	2,366	0.973 (0.915–1.035)	0.357
WC per 1 cm, mutually adjusted for BMI	2,366	1.041 (1.015–1.068)	0.004

Note. Model 3 adjusted for age, sex, race/ethnicity, smoking status, and physical activity. The mutually adjusted model included BMI and WC simultaneously. ORs are prevalence odds ratios. BMI, body mass index; CI, confidence interval; IFG, impaired fasting glucose; OR, odds ratio; WC, waist circumference.

Table 3 Survey-weighted associations of BMI-WC phenotypes with prevalent IFG.

BMI-WC phenotype contrast	Unweighted n	OR (95% CI)	P value
BMI <25 + WC elevated vs BMI <25 + WC not elevated	60	2.321 (0.756–7.123)	0.130
BMI ≥25 + WC not elevated vs BMI <25 + WC not elevated	365	1.246 (0.913–1.700)	0.153
BMI ≥25 + WC elevated vs BMI <25 + WC not elevated	1,265	2.802 (2.155–3.644)	<0.001

Note. Reference: BMI <25 kg/m^2 plus non-elevated WC. Models adjusted for age, sex, race/ethnicity, smoking status, and physical activity. BMI, body mass index; CI, confidence interval; IFG, impaired fasting glucose; OR, odds ratio; WC, waist circumference.

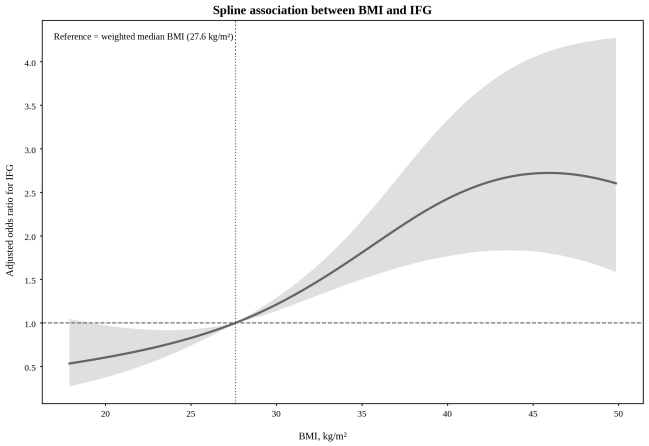

Figure. 2A Survey-weighted adjusted spline association between BMI and prevalent IFG. The spline was refitted after defining the full positive-weight survey design and restricting the analytic subpopulation by domain analysis. The weighted median BMI is the reference. BMI, body mass index; CI, confidence interval; IFG, impaired fasting glucose; OR, odds ratio.

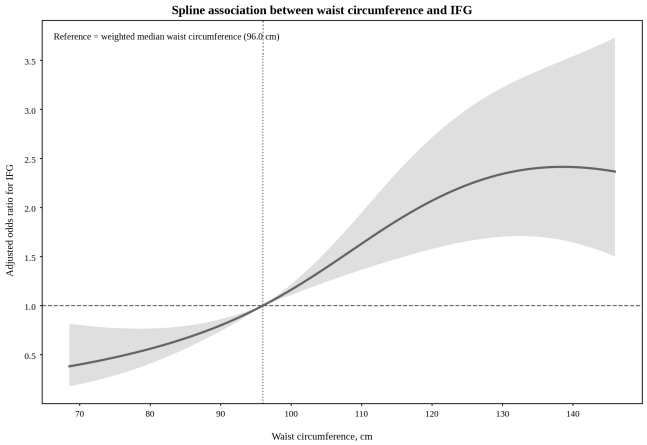

Figure. 2B Survey-weighted adjusted spline association between WC and prevalent IFG. The spline was refitted after defining the full positive-weight survey design and restricting the analytic subpopulation by domain analysis. The weighted median WC is the reference. CI, confidence interval; IFG, impaired fasting glucose; OR, odds ratio; WC, waist circumference.

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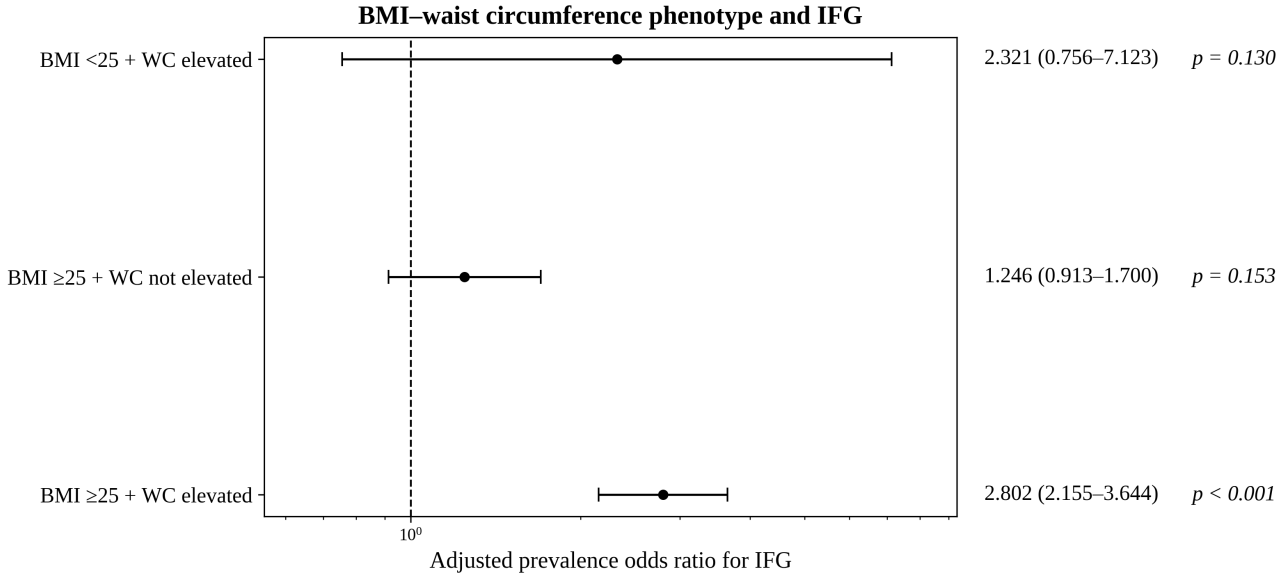

Figure. 3 BMI-WC phenotypes and prevalent IFG. Points and horizontal lines show fully adjusted prevalence ORs and 95% CIs. The reference phenotype was BMI <25 kg/m^2 plus non-elevated WC. BMI, body mass index; CI, confidence interval; IFG, impaired fasting glucose; OR, odds ratio; WC, waist circumference.

cally distinct groups, but larger samples are needed for precise estimates in this specific NHANES cycle [14].

Several sensitivity analyses supported the main interpretation while also showing why conclusions should remain bounded. HbA1c-defined prediabetes was associated with BMI and WC in separate models, whereas neither anthropometric term reached statistical significance after mutual adjustment. Alternative age specification and extended socioeconomic adjustment produced results similar to the primary IFG models. Together, these analyses indicate that the separate associations are reproducible across outcome and covariate specifications, while the relative conditional behavior of BMI and WC is more model-dependent.

Strengths of this study include use of recent NHANES data, the fasting-subsample weight, masked strata and PSU variables, a survey-domain design constructed before analytic restrictions, explicit accounting for exclusion and covariate missingness, and multiple complementary exposure specifications. The analysis also reports the HbA1c sensitivity population and numerical mutually adjusted estimates, and provides detailed variable definitions and reproducible analysis code in the

Supplementary Material.

Limitations should be considered. First, the cross-sectional design precludes temporal or causal inference, and the reported ORs describe prevalent rather than incident IFG. Second, FPG and HbA1c were measured at a survey time point and oral glucose tolerance testing was not incorporated. Third, residual confounding is possible despite demographic, smoking, activity, and socioeconomic adjustment. Fourth, BMI and WC are anthropometric proxies and do not directly quantify visceral or ectopic fat. Finally, the normal-BMI elevated-WC phenotype was uncommon in this analytic sample, limiting precision for that subgroup.

Conclusions

In the defined NHANES 2021–2023 adult fasting subpopulation meeting the analytic criteria, BMI and WC were each associated with prevalent IFG when modeled separately. In a mutually adjusted model, WC remained associated with IFG while BMI did not, but this conditional result should not be interpreted as evidence of statistical or predictive superiority. The combined BMI-WC phenotypes further described heterogeneity in prevalent IFG odds.

Declarations

Ethics approval and consent to participate: NHANES data are publicly available and de-identified. NHANES protocols are reviewed by the NCHS Ethics Review Board; no additional ethics approval or participant re-consent was required for this secondary analysis.

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Consent for publication: Not applicable.

Availability of data and materials: NHANES August 2021–August 2023 data are publicly available from the National Center for Health Statistics. A reproducible variable-definition table and analysis script are provided in the Supplementary Material.

Competing interests: The authors declare no competing interests.

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