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# Racial and ethnic disparities in the burden of non-obese type 2 diabetes using different anthropometric measurements

Junyu Sui [a,b], Bei Wu [a], Yaguang Zheng [a], Zhiyue Mo [c], Qianyu Dong [d,e], Lan N. Đoàn [f], Stella S. Yi [f], Xiang Qi [a,*]

[a] Rory Meyers College of Nursing, New York University, New York, NY, 10010, USA
[b] School of Global Public Health, New York University, New York, NY, 10003, USA
[c] NYU Steinhardt School of Culture, Education, and Human Development, New York University, New York, NY, 10003, USA
[d] Department of Statistics, University of California, Santa Cruz, USA
[e] Baskin School of Engineering, Santa Cruz, CA, 95064, USA
[f] Department of Population Health, Section for Health Equity, NYU Grossman School of Medicine, New York, NY, 10016, USA

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ABSTRACT

*Aims:* Compare racial/ethnic disparities in the prevalence of non-obese type 2 diabetes (T2D) and the proportion of non-obese individuals among T2D patients.
*Methods:* This cross-sectional study used ICD-9/10 codes to ascertain T2D. Participants were classified as non-obese by BMI (<25 kg/m$^2$ for normal weight; <23 kg/m$^2$ for Asian Americans), waist circumference (<102 cm for males, <88 cm for females), and waist-to-hip ratio (<0.9 for males, <0.85 for females). The statistical analysis used marginal standardization of predicted probabilities from multivariable logistic regression to calculate the prevalence.
*Key results:* Among 276,736 participants (mean age 51.7, 61.2% female), non-obese T2D prevalence varied: 6.85% (BMI), 4.17% (waist circumference), 3.63% (waist-to-hip ratio). Asian participants had the highest prevalence of normal-weight T2D (2.70% vs. 1.92% in White, OR 1.44, 95% CI: 1.22–1.69) and non-obese T2D by waist circumference (8.04% vs. 3.36%, OR 2.61, 95% CI: 2.35–2.89). Black participants had the highest prevalence using waist-to-hip ratio (5.37% vs. 2.91%, OR 1.91, 95% CI: 1.80–2.03).
*Conclusion:* Asian Americans showed higher non-obese T2D prevalence by BMI and waist circumference, while Black adults had higher prevalence by waist-to-hip ratio, suggesting different fat distribution patterns.

## 1. Introduction

Diabetes mellitus is one of the most prevalent chronic diseases affecting 38.4 million individuals in the United States (US) (CDC, 2024). While obesity is a major risk factor for type 2 diabetes (T2D), (Risk Factors for Diabetes - NIDDK) an emerging trend of non-obese T2D challenges the current understanding of diabetes pathogenesis and treatment approaches (Gujral et al., 2018; Esser et al., 2020). Non-obese T2D differs from obesity-induced T2D in its characteristics of insulin resistance and islet β-cell dysfunction (Esser et al., 2020). T2D patients with normal weight typically exhibit worse β-cell function but preserved insulin sensitivity and higher

* Corresponding author. Rory Meyers College of Nursing, New York University, New York, 10010, USA.
*E-mail address:* xq450@nyu.edu (X. Qi).

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mortality rates than their obese counterparts (Fan et al., 2024; Stefan et al., 2017; Kobayashi et al., 2023). These distinctions require specific treatment strategies, as lifestyle interventions effective for obese T2D individuals may not be equally beneficial for non-obese T2D individuals. For instance, strength training is more effective than aerobic exercise for glycemic control in T2D patients with normal weight, but with contradictory findings in obese groups (Kobayashi et al., 2023). Additionally, non-obese T2D is an increasing issue in the US. Data from the 2015–2020 Behavioral Risk Factor Surveillance System identified significant increases in diabetes prevalence among normal-weight individuals (body mass index [BMI]<25.0 kg/$m^2$) for Black (41.5% increase), Hispanic (30.9% increases) and White (15.8% increases) adults, while no significant increase was observed among Asian individuals (Adesoba and Brown, 2023). Therefore, identifying populations at risk of non-obese T2D is critical for the development of targeted prevention strategies.

T2D disproportionately affects racial and ethnic minoritized groups in the US, with higher prevalence among Hispanic, Black, and Asian adults compared to White adults (Cheng et al., 2019). These disparities can be attributed to various factors, including socio-economic status, healthcare access, cultural dietary patterns, and genetic predisposition (Walker et al., 2016; Chatterjee et al., 2015). For example, Asian Americans may be influenced by cultural dietary patterns relying on carbohydrate rich food and genetic factors that promote β-cell dysfunction and visceral adiposity at lower BMI compared to other racial and ethnic groups (Vijayan et al., 2023). One study using National Health and Nutrition Examination Surveys (NHANES) data reported that after BMI adjustment, Asian (27.0%) and Hispanic (20.3%) adults exhibited the highest diabetes prevalence compared to Black and White adults (Cheng et al., 2019).

The standardized measurement for classifying obesity remains contentious in its applicability across different racial/ethnic groups.

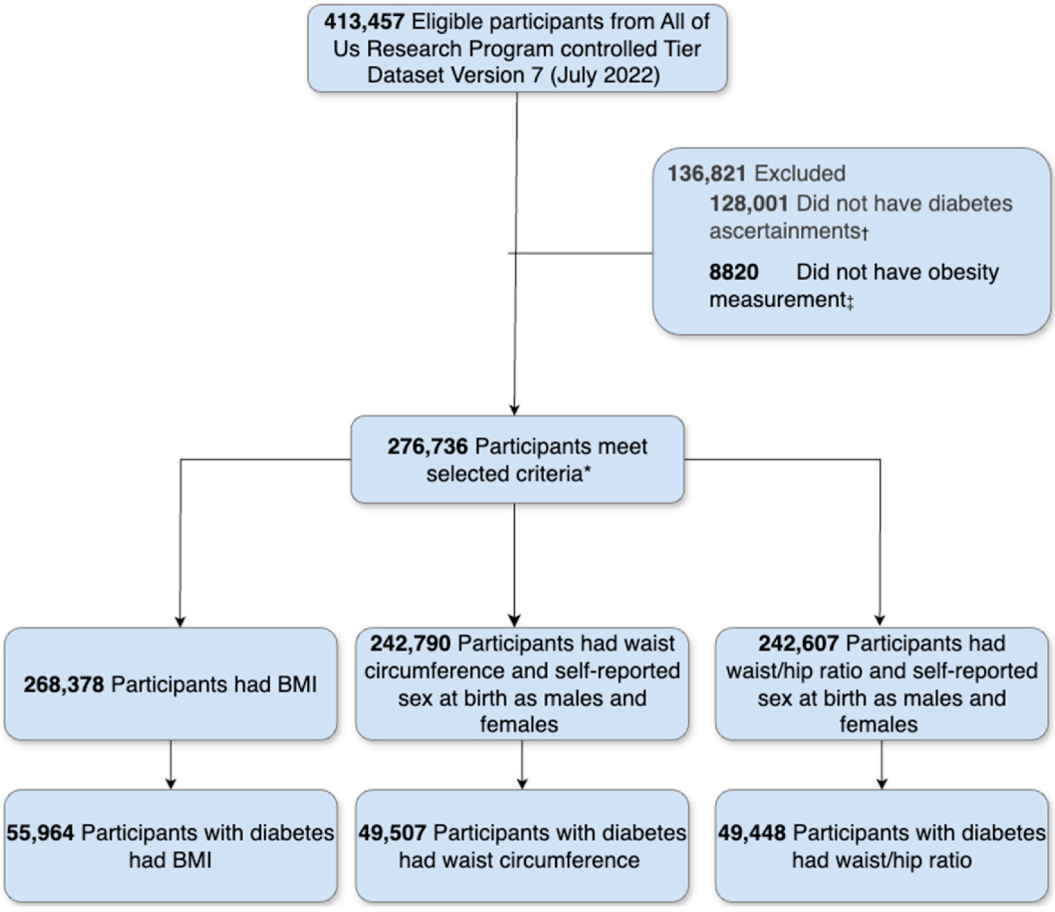


**Fig. 1.** Flow Chart of Sample Selection

Abbreviations: BMI, Body Mass Index.

* Inclusion criteria required participants to have at least one electronic health records (EHR) for type 2 diabetes ascertainments and at least one physical measurement for obesity classification (BMI, waist circumference, or hip circumference). Participants must self-report their sex at birth as either male or female.

† Diabetes ascertainments are diagnosis codes from EHR based on the International Classification of Diseases, Ninth and Tenth Revision, and Clinical Modification.

‡ Obesity measurements are computed BMI (divided a participant's weight by height squared), measured waist circumference, and waist-to-hip ratio (divided a participant's waist circumference by hip circumference).

Although obesity has been traditionally recognized using a BMI range ($\geq$27.5 kg/m$^2$ for Asian or $\geq$30 kg/m$^2$ for other racial/ethnic groups), waist circumference and waist-to-hip ratio have increasingly challenged the reliance on BMI as the primary metric for obesity classification (Hewage et al., 2023; Parente et al., 2020). Different anthropometric measurements provide insights into specific aspects of body composition, such as central obesity and overall fat distribution, that BMI may not fully capture (Sahakyan et al., 2015). Human body fat distribution is heterogeneous across racial and ethnic groups, complicating the interpretation of these measures in the context of T2D risk (Lim et al., 2019).

However, there remains little research examining different anthropometric measures for investigating racial and ethnic differences in the prevalence of non-obese T2D and the proportion of non-obese patients with T2D. To address the gaps, we used the data from the All of Us (AoU) Research Program, a racially and ethnically diverse cohort initiated by the National Institutes of Health. The dataset emphasizes racial inclusivity, with approximately 50% of participants from minoritized and traditionally understudied populations. We hypothesized that both the prevalence and proportion of non-obese T2D would vary significantly across racial and ethnic groups, and that these variations would be differentially captured by distinct obesity indicators.

## 2. Methods

### 2.1. Data source and study population

This cross-sectional study used data from the AoU, a population-based cohort collecting comprehensive health information from US adults between 2017 and 2022. The AoU dataset includes surveys, electronic health records (EHR), and physical measurements. The AoU Institutional Review Board approved all study procedures. Participants have given informed consent upon joining the AoU, including consent to access their EHR, physical measurements, and surveys. We performed all analyses in accordance with the AoU Code of Conduct.

The study sample was derived from the Controlled Tier Dataset Version 7 (data as of July 2022), comprising 413,457 participants. Inclusion criteria include having available EHR for T2D ascertainments and at least one physical measurement for obesity classification (BMI, waist circumference, or waist-to-hip ratio). Sex at birth was self-reported through the basic survey question: "What was your biological sex assigned at birth?" and the answer includes: 1) Male, 2) Female, 3) Intersex, 4) None of these, 5) Prefer not to answer, 6) Skip. Participants who reported as male or female were included in sex-specific obesity measurements based on waist circumference and waist-to-hip ratio, and all participants were included when using BMI. Among 287,012 participants have T2D ascertainments, a total of 276,736 participants met all criteria and were subsequently divided into three groups based on three obesity indicators (flowchart for sample selection in Fig. 1).

### 2.2. Race and ethnicity

Race and ethnicity were self-reported through the basic survey. Participants were asked: "Which categories describe you?" and the answers include: 1) American Indian or Alaska Native; 2) Black, African American, or African; 3) Asian; 4) Hispanic, Latino, or Spanish; 5) Middle Eastern or North African; 6) Native Hawaiian or Other Pacific Islander; 7) White; 8) None of these describe me; 9) Prefer not to answer. As where sample sizes for specific groups were too small for statistical analysis, our study focused on adults who identified themselves as: Asian, White, Black, and Hispanic. We combined participants who selected multiple categories or chose options other than the four groups as 'other' race and ethnicity category.

### 2.3. Anthropometric measurements for obesity

Anthropometric indices were derived from physical measurements collected in the AoU, including computed BMI (participant's weight in kilograms divided by height in meters squared), measured waist circumference, and waist-to-hip ratio (divided a participant's waist circumference in centimeters by hip circumference in centimeters). The average values were calculated for multiple waist circumference and hip circumference measurements. The classifications of normal-weight, overweight, and obesity were based on World Health Organization guidelines (World Health Organization, 2024). Using BMI, under- and normal-weight was defined as BMI$<$25 kg/m$^2$, overweight as 25 $\leq$ BMI$<$30 kg/m$^2$, and obese as BMI$\geq$30 kg/m$^2$. Using waist circumference, non-obese was defined as having a waist circumference $<$102 cm for males and $<$88 cm for females, and obese as having waist circumference $\geq$102 cm for males and $\geq$88 cm for females. Using waist-to-hip ratio, non-obese was defined as having waist-to-hip ratio $<$0.9 for males and $<$0.85 for females, and obese as having waist-to-hip ratio $\geq$0.9 for males and $\geq$0.85 for females. Due to the lack of conclusive BMI cutoffs for Asian Americans (Bajaj et al., 2024), we applied ethnicity-specific cutoffs recommended by previous studies (Hsu et al., 2014; Appropriate body, 2004): underweight/normal-weight (BMI $<$23 kg/m$^2$), overweight (23 $\leq$ BMI$<$27.5 kg/m$^2$), and obese (BMI$\geq$27.5 kg/m$^2$).

### 2.4. Type 2 diabetes

We identified cases of T2D from the EHR data, according to corresponding codes of the International Classification of Diseases (ICD-9/10-CM) (Appendix Table 1).

### 2.5. Covariates

Covariates were selected based on previous studies on the risk factors for T2D (Walker et al., 2016; Berkowitz et al., 2014), including age, sex at birth (only when using BMI as the obesity indicator), income, education, and neighborhood deprivation index. Age was calculated as the difference between the participant's date of birth and enrollment date in the AoU, and categorized into three groups: 18–44, 45–59, and ≥65 years. Education level was categorized as less than high school, high school diploma or equivalent, some college, college degree or higher, and skip/prefer not to answer. Income was categorized as <$25k, $25k-50k, $50k-75k, $75k-100k, >$100k, and skip/prefer not to answer. The neighborhood deprivation index is a composite measurement using principal component analysis of census variables across multiple sociodemographic domains to assess the level of neighborhood socioeconomic disadvantage (Messer et al., 2006). The index is categorized into quartiles: <25th percentile, 25th-50th percentile, 50th-75th percentile, and >75th percentile. Higher scores indicate more disadvantaged neighborhood socioeconomic status.

### 2.6. Statistical analysis

Descriptive statistics were calculated for all variables. Continuous variables were summarized using mean (standard deviation [SD]) and compared across races and ethnicities using ANOVA. Categorical variables were presented as frequencies (percentages) and compared using the Chi-squared test. We calculated the age-adjusted (age- and sex-adjusted for BMI) and fully-adjusted (additionally adjusted for education, income, and neighborhood deprivation index) prevalence by using marginal standardization of predicted probabilities from multivariable logistic regression models using three obesity indicators across racial and ethnic groups. The 95% Confidence intervals for the age-adjusted and fully-adjusted prevalence was calculated by Bootstrap through 100 iterations. We also calculated the crude, age-adjusted and fully-adjusted non-obese T2D proportions among participants with T2D using the same approach. Additionally, we used multivariable logistic regression models to estimate the racial and ethnic differences (odds ratio [OR] and 95% CI) in non-obese T2D prevalence for all participants and proportion of non-obese individuals from patients with T2D by different anthropometric measures. For all results, P-values were two-sided and the value less than 0.05 was considered significant. Data cleaning and analysis were performed using the Python Cloud analysis environment within the AoU Research Workbench.

### 2.7. Sensitivity analysis

As evidence indicated that non-Hispanic Asian Americans demonstrate unique adiposity patterns compared with other racial/ethnic groups (Liu et al., 2021). We conducted two sensitivity analyses. First, we calculated the prevalence of T2D by second-level subgroups using waist circumference and waist-to-hip ratio within the same BMI category stratified by race/ethnicity and sex at birth. Second, we calculated T2D prevalence and odds ratios across different obesity phenotypes stratified by race/ethnicity, including 1) normal in all anthropometric measurements (BMI <23 kg/m$^2$ for Asian participants and <25 kg/m$^2$ for others; waist circumference <102 for males and <88 for females; waist-to-hip ratio <0.9 for males and <0.85 for females); 2) normal in BMI with high in waist circumference; 3) normal in BMI with high in waist-to-hip ratio; 4) high in BMI with normal in waist circumference; 5) high in BMI with normal in waist-to-hip ratio; and 6) high in all anthropometric measurements. For all analyses, we calculated crude, age-adjusted, and fully adjusted prevalence using marginal standardization of predicted probabilities from multivariable logistic regression models.

## 3. Results

Table 1 presents the socio-demographic characteristics of the study participants. Of all participants, 3.15% are Asian, 54.28% are White, 20.78% are Black, 18.01% are Hispanic individuals, and 3.79% are from other race and ethnicity groups. Asian participants were the youngest group, with 51.62% aged between 18 and 44 years. Black participants had the highest proportion in the 45–64 age group, and White participants had the largest representation in the age≥65 group. A total of 61.24% participants were female, and Hispanic adults had the highest proportion of female participants (67.75%). Educational levels varied, with 14.69% Hispanic participants having less than a high school education, and 77.37% Asian participants holding a college degree or higher. Neighborhood deprivation index and income displayed significant variations, with White and Asian participants exhibiting significantly more advantageous socioeconomic conditions compared to Black and Hispanic participants.

Anthropometric measurements revealed notable differences across racial and ethnic groups. The mean BMI for the entire participants was 29.90 kg/m$^2$ (SD 7.64), with Asian participants having the lowest mean BMI at 25.62 (SD 5.59) and Black participants having the highest mean BMI at 31.45 (SD 8.73). Using ethnicity-specific BMI cutoffs, 69.77% Asian participants were non-obese, compared with 49.37% in Hispanics and 49.09% in Black participants. Mean waist circumference was 96.73 cm (SD 18.0), with Asian participants having the lowest mean waist circumference at 84.80 cm (SD 14.45) and Black participants having the highest mean waist circumference at 99.64 cm (SD 18.53). Regarding waist-to-hip ratio, Asian participants had the lowest mean waist-to-hip ratio at 0.86 compared to the overall cohort mean of 0.89. While White, Black and Hispanic participants had similar mean waist-to-hip ratio values of approximately 0.89.

Table 2 displays the crude, age-adjusted (age- and sex-adjusted for BMI), and fully-adjusted prevalence of non-obese T2D. Using ethnicity-specific BMI cutoffs, Asian participants displayed the highest normal-weight T2D prevalence at 2.7% (95% CI: 2.45–3.01). Using waist circumference, Asian participants demonstrated the highest non-obese T2D prevalence at 8.04% (95% CI: 7.68–8.49). White participants had the lowest non-obese T2D prevalence compared to other racial and ethnic groups. Using the waist-to-hip ratio indicator, Black participants had the highest non-obese T2D prevalence at 5.37% (95% CI: 5.15–5.59).

**Table 1**
Characteristics of participants by race/ethnicity in the all of us research program.

| Characteristic | Overall | Asian | White | Black | Hispanic | Other | P-Value |
|---|---|---|---|---|---|---|---|
| N (%) | 276,736 | 8714 (3.15) | 150,206 (54.28) | 57,485 (20.78) | 49,845 (18.01) | 10,486 (3.79) | |
| **Age category, n (%)** | | | | | | | <0.001 |
| 18–44 | 83,550 (30.19) | 4498 (51.62) | 37,644 (25.06) | 16,413 (28.55) | 21,827 (43.79) | 3168 (30.21) | |
| 40–59 | 100,544 (36.33) | 2591 (29.73) | 47,337 (31.51) | 27,780 (48.33) | 19,164 (38.45) | 3672 (35.02) | |
| 65+ | 92,642 (33.48) | 1625 (18.65) | 65,225 (43.42) | 13,292 (23.12) | 8854 (17.76) | 3646 (34.77) | |
| **Sex at birth, n (%)** | | | | | | | <0.001 |
| Female | 169,463 (61.24) | 5380 (61.74) | 90,521 (60.26) | 33,861 (58.90) | 33,772 (67.75) | 5929 (56.54) | |
| Male | 107,273 (38.76) | 3334 (38.26) | 59,685 (39.74) | 23,624 (41.10) | 16,073 (32.25) | 4557 (43.46) | |
| **Income, n (%)** | | | | | | | <0.001 |
| <25k | 72,856 (26.33) | 1098 (12.60) | 25,018 (16.66) | 28,203 (49.06) | 15,695 (31.49) | 2842 (27.10) | |
| 25k-50k | 19,763 (7.14) | 465 (5.34) | 10,316 (6.87) | 4283 (7.45) | 3994 (8.01) | 705 (6.72) | |
| 50k-75k | 28,411 (10.27) | 994 (11.41) | 20,054 (13.35) | 3259 (5.67) | 3213 (6.45) | 891 (8.50) | |
| 75k-100k | 21,692 (7.84) | 873 (10.02) | 16,678 (11.10) | 1603 (2.79) | 1838 (3.69) | 700 (6.68) | |
| >100k | 55,466 (20.04) | 2929 (33.61) | 45,574 (30.34) | 2348 (4.08) | 2944 (5.91) | 1671 (15.94) | |
| Skip or PNA | 56,879 (20.55) | 1669 (19.15) | 19,565 (13.03) | 14,229 (24.75) | 18,535 (37.19) | 2881 (27.47) | |
| **Education, n (%)** | | | | | | | <0.001 |
| Less than high school | 9544 (3.45) | 52 (0.60) | 825 (0.55) | 1110 (1.93) | 7323 (14.69) | 234 (2.23) | |
| High school diploma or equivalent | 73,195 (26.45) | 587 (6.74) | 24,041 (16.01) | 27,017 (47.00) | 18,854 (37.83) | 2696 (25.71) | |
| Some college | 71,077 (25.68) | 1230 (14.12) | 38,882 (25.89) | 16,270 (28.30) | 12,126 (24.33) | 2569 (24.50) | |
| College degree or higher | 116,904 (42.24) | 6742 (77.37) | 85,037 (56.61) | 10,663 (18.55) | 10,107 (20.28) | 4355 (41.53) | |
| Skip or PNA | 6016 (2.17) | 103 (1.18) | 1421 (0.95) | 2425 (4.22) | 1435 (2.88) | 632 (6.03) | |
| **Deprivation index, n (%)** | | | | | | | <0.001 |
| <25th percentile | 69,378 (25.07) | 2841 (32.60) | 53,363 (35.53) | 4893 (8.51) | 5545 (11.12) | 2736 (26.09) | |
| 25th-50th percentile | 68,991 (24.93) | 2594 (29.77) | 38,993 (25.96) | 10,819 (18.82) | 13,974 (28.03) | 2611 (24.90) | |
| 50th-75th percentile | 69,852 (25.24) | 1783 (20.46) | 38,822 (25.85) | 15,644 (27.21) | 11,026 (22.12) | 2577 (24.58) | |
| >75th percentile | 68,515 (24.76) | 1496 (17.17) | 19,028 (12.67) | 26,129 (45.45) | 19,300 (38.72) | 2562 (24.43) | |
| **BMI, mean (SD)**[a] | 29.90 (7.64) | 25.62 (5.59) | 29.29 (7.22) | 31.45 (8.73) | 30.76 (7.30) | 29.54 (7.52) | <0.001 |
| Normal weight, n (%) | 74,179 (26.80) | 2912 (33.42) | 43,515 (28.97) | 13,683 (23.80) | 9520 (19.10) | 2962 (28.25) | |
| Overweight, n (%) | 81,992 (29.63) | 3168 (36.36) | 46,595 (31.02) | 14,537 (25.29) | 15,089 (30.27) | 3186 (30.38) | |
| Obese, n (%) | 120,565 (43.57) | 2634 (30.23) | 60,096 (40.01) | 29,265 (50.91) | 25,236 (50.63) | 4338 (41.37) | |
| **Waist circumference, mean (SD)**[b] | 96.73 (17.98) | 84.80 (14.45) | 96.11 (18.00) | 99.64 (18.53) | 97.26 (16.87) | 96.31 (17.64) | <0.001 |
| Non-obese male | 53,157 (19.21) | 2408 (27.63) | 27,016 (17.99) | 13,713 (23.85) | 7703 (15.45) | 2317 (22.10) | |
| Non-obese female | 58,246 (21.05) | 3399 (39.01) | 36,011 (23.97) | 7562 (13.15) | 9299 (18.66) | 1975 (18.83) | |
| Obese male | 52,374 (18.93) | 874 (10.03) | 31,785 (21.16) | 9461 (16.46) | 8199 (16.45) | 2055 (19.60) | |
| Obese female | 112,959 (40.82) | 2033 (23.33) | 55,394 (36.88) | 26,749 (46.53) | 24,644 (49.44) | 4139 (39.47) | |
| **Hip circumference, mean (SD)** | 108.69 (15.40) | 98.73 (11.08) | 108.27 (14.76) | 111.47 (17.35) | 108.53 (14.56) | 107.80 (15.04) | <0.001 |
| **Waist-to-hip ratio, mean (SD)** [c] | 0.89 (0.10) | 0.86 (0.09) | 0.88 (0.11) | 0.89 (0.11) | 0.90 (0.11) | 0.89 (0.10) | <0.001 |
| Non-obese male | 27,804 (10.05) | 1391 (15.96) | 12,853 (8.56) | 8858 (15.41) | 3448 (6.92) | 1254 (11.96) | |
| Non-obese female | 73,066 (26.40) | 2921 (33.52) | 43,758 (29.13) | 12,306 (21.41) | 11,708 (23.49) | 2373 (22.63) | |

(*continued on next page*)

**Table 1** (*continued*)

| Characteristic | Overall | Asian | White | Black | Hispanic | Other | P-Value |
|---|---|---|---|---|---|---|---|
| Obese female | 98,139 (35.46) | 2511 (28.82) | 47,647 (31.72) | 22,005 (38.28) | 22,235 (44.61) | 3741 (35.68) | |
| Obese male | 77,727 (28.09) | 1891 (21.70) | 45,948 (30.59) | 14,316 (24.90) | 12,454 (24.99) | 3118 (29.73) | |

Abbreviations: BMI, body mass index; Other race and ethnicity includes American Indian/Alaska Native (n = 824), Middle Eastern or North African (n = 2771), Native Hawaiian or Pacific Islander (n = 662), those selecting "None of these describe me," (n = 2549) and those who preferred not to answer (n = 3680).

[a] Participants were categorized as underweight or normal-weight (BMI<25 kg/m$^2$), overweight (25 ≤ BMI<30 kg/m$^2$), and obese (BMI≥30 kg/m$^2$). Asian Americans were categorized using the ethnicity-specific BMI cutoffs: underweight and normal-weight (BMI<23 kg/m$^2$), overweight (23 ≤ BMI<27.5 kg/m$^2$), and obese (BMI≥27.5 kg/m$^2$).

[b] All male participants were categorized as non-obese (waist circumference<102 cm) and obese (waist circumference≥102 cm). All female participants were categorized as non-obese (waist circumference<88 cm) and obese ((waist circumference≥88 cm).

[c] All male participants were categorized as non-obese (waist-to-hip ratio<0.9) and obese (waist-to-hip ratio≥0.9). All female participants were categorized as non-obese (waist-to-hip ratio<0.85) and obese (waist-to-hip ratio≥ 0.85).

Table 3 illustrates the crude, age-adjusted (age- and sex-adjusted for BMI), and fully-adjusted non-obese proportion among patients with T2D. Using BMI, Asian participants had the highest proportion of normal-weight and overweight individuals among patients with T2D. Applying the Asian ethnicity-specific BMI cutoffs only significantly decreased the proportion normal-weight but not overweight individuals. Using waist circumference, Asian participants had the highest proportion of non-obese individuals at 46.34% (95% CI: 42.51–50.41). Using waist-to-hip ratio, Black participants showed the highest proportion at 22.90% (95% CI: 22.53–23.63).

Table 4 displays the association between race/ethnicity and non-obese T2D. All comparisons are made with White participants as the reference group. Using ethnicity-specific BMI cutoffs, Asian participants demonstrated the highest odds for normal-weight T2D (OR, 1.44; 95% CI: 1.22–1.69). Using waist circumference, Asian participants displayed significantly higher odds of non-obese T2D at 2.61 (95% CI: 2.35–2.89). However, using waist-to-hip ratio, Black participants showed the highest odds of non-obese T2D at 1.91 (95% CI: 1.80–2.03). Among patients with T2D, Asian participants had the highest odds of normal-weight at 1.26 (95% CI: 1.06–1.51) using ethnicity-specific BMI cutoffs. Similarly, using waist circumference, Asian participants showed significantly higher odds at 3.52 (95% CI: 3.05–4.07). Using waist-to-hip ratio, Black participants had the highest OR at 1.27 (95% CI: 1.19–1.35).

The results of sensitivity analysis (Appendix Tables 2–5) revealed similar racial disparities in T2D prevalence. Although waist circumference and waist-to-hip ratio did not differ significantly within the normal BMI category (BMI <23 kg/m$^2$ for Asian and BMI <25 kg/m$^2$ for all the other races and ethnicities) across racial and ethnic groups (Appendix Table 2), Asian adults had higher fully-adjusted prevalence of non-obese T2D when assessed using either normal waist circumference (2.40%, 95% CI: 1.95–2.81) or normal waist-to-hip ratio (1.14%, 95% CI: 0.88–1.39) compared to other groups (Appendix Table 3). As shown in Appendix Tables 4 and 5, among Asian adults, higher T2D prevalence was observed in several distinct phenotypes. These included normal BMI with normal waist circumference and waist-to-hip ratio (1.05%, 95% CI: 0.75–1.21), normal BMI with high waist-to-hip ratio (1.31%, 95% CI: 1.07–1.31), and high BMI with normal waist circumference (5.75%, 95% CI: 5.14–6.45). Additionally, compared with individuals with normal BMI, waist-to-hip ratio, and waist circumference, the odds of T2D for those with normal BMI but high waist-to-hip ratio (OR: 3.38, 95% CI: 3.08–3.72) or high waist circumference (OR: 2.23, 95% CI: 2.09–2.38) are higher than those with high BMI but normal waist circumference (OR: 2.10; 95% CI: 1.99–2.21). These results indicated that visceral fat accumulation measured by waist circumference or waist-to-hip ratio would be a better predictor for T2D than obesity measured by BMI.

## 4. Discussion

Using a large, diverse, and population-based dataset, this study revealed significant racial and ethnic disparities in normal-weight and non-obese T2D prevalence and proportion among T2D patients in the US. Using BMI and waist circumference cutoffs, Asian adults demonstrated the highest prevalence of normal-weight T2D, lowest mean waist circumference, and the highest proportion of non-obese individuals among T2D patients. When considering waist-to-hip ratio, Black adults showed the highest non-obese T2D prevalence and, despite similar mean ratios to other groups, had significantly higher mean waist and hip circumferences and non-obese proportions among T2D patients. The results from multivariable models further quantified the disparities: with White individuals as the reference group, Asian participants had the highest odds of normal-weight T2D when using BMI and the highest odds of non-obese T2D using waist circumference, while Black adults had the highest odds using waist-to-hip ratio.

Our findings across different racial and ethnic groups were consistent with previous studies investigating T2D among non-obese individuals. The age- and sex-adjusted prevalence for Asian participants using general (10.46%) and ethnicity-specific (8.07%) BMI cutoff closely aligned with the age- and sex-standardized T2D prevalence among non-obese Asian individuals from the 1997–2005 National Health Interview Survey, which showed 10.72% prevalence using general and 8.89% using ethnicity-specific BMI standards (Oza-Frank et al., 2009). Additionally, the non-obese T2D prevalence among White (4.82%), Black (8.49%) and Hispanic (11.41%) groups fell within the range of prevalence in diagnosed T2D using the 1971–2004 National Health and Nutrition Examination Surveys (Zhang et al., 2009). Meanwhile, our results on racial and ethnic disparities in obesity using both BMI and waist circumference corroborated with previous study (Karnes et al., 2021), showing stronger disparities among Black and Hispanic compared to Asian and

**Table 2**
The prevalence of type 2 diabetes among all of us participants using different anthropometric measurements.

| | Asian | | White[a] | Black[a] | Hispanic[a] | Others[a] |
|---|---|---|---|---|---|---|
| | General cutoff[a] | Ethnicity-specific cutoff[b] | | | | |
| **Using BMI indicator** | | | | | | |
| Prevalence of **Normal-weight** T2D[e] | | | | | | |
| Crude, % (95% CI) | 3.54 (3.15–3.93) | 1.88 (1.59–2.16) | 1.87 (1.80–1.94) | 2.76 (2.63–2.90) | 2.39 (2.25–2.52) | 2.65 (2.33–2.96) |
| Age-and sex-adjusted[c],% (95% CI) | 4.60 (4.40–5.10) | 2.46 (2.14–2.84) | 1.71 (1.16–1.18) | 3.00 (2.80–3.10) | 3.00 (2.90–3.10) | 2.60 (2.30–2.70) |
| Fully-adjusted[d],% (95% CI) | 5.15 (4.41–5.48) | 2.70 (2.45–3.01) | 1.92 (1.92–2.05) | 2.51 (2.44–2.66) | 2.46 (2.29–2.43) | 2.54 (2.25–2.69) |
| Prevalence of **Overweight** T2D[e] | | | | | | |
| Crude, % (95% CI) | 4.13 (3.71–4.55) | 3.99 (3.57–4.40) | 4.02 (3.92–4.12) | 4.97 (4.79–5.14) | 6.29 (6.07–6.51) | 5.38 (4.94–5.82) |
| Age-and sex-adjusted[c],% (95% CI) | 5.86 (5.30–6.05) | 5.61 (5.42–6.05) | 3.65 (3.50–3.60) | 5.49 (5.23–5.47) | 8.41 (8.20–8.80) | 5.25 (4.90–5.43) |
| Fully-adjusted[d],% (95% CI) | 6.46 (5.95–7.01) | 6.23 (6.15–6.64) | 3.81 (3.72–3.96) | 5.04 (4.74–5.16) | 7.05 (6.81–7.27) | 5.22 (4.95–5.34) |
| Prevalence of **Obese** T2D[e] | | | | | | |
| Crude, % (95% CI) | 4.16 (3.74–4.59) | 5.97 (5.47–6.47) | 9.89 (9.74–10.04) | 15.57 (15.27–15.87) | 13.71 (13.40–14.02) | 11.65 (11.02–12.27) |
| Age-and sex-adjusted[c],% (95% CI) | 5.31 (4.80–5.80) | 7.56 (7.01–7.94) | 9.40 (9.30–9.40) | 15.65 (15.5–15.8) | 15.70 (15.5–15.9) | 11.76 (11.2–12.4) |
| Fully-adjusted[d],% (95% CI) | 6.53 (5.94–6.85) | 9.33 (8.65–9.81) | 10.13 (10.04–10.24) | 13.94 (13.63–14.38) | 13.9 (13.64–14.16) | 11.52 (11.17–12.67) |
| **Using waist circumference indicator** | | | | | | |
| Prevalence of **Non-obese** T2D [e] | | | | | | |
| Crude, % (95% CI) | 5.77 (5.25–6.30) | | 3.33 (5.23–3.42) | 4.81 (4.63–5.00) | 5.54 (5.32–5.76) | 5.04 (4.59–5.49) |
| Age-adjusted[c],% (95% CI) | 7.48 (6.73–8.32) | | 3.09 (3.03–3.14) | 5.05 (4.94–5.27) | 6.92 (6.70–7.03) | 4.81 (4.98–5.25) |
| Fully-adjusted e[d],% (95% CI) | 8.04 (7.68–8.49) | | 3.36 (3.25–3.47) | 4.61 (4.54–4.73) | 5.81 (5.69–5.92) | 4.70 (4.37–5.03) |
| Prevalence of **Obese** T2D[e] | | | | | | |
| Crude, % (95% CI) | 6.17 (5.62–6.63) | | 11.92 (11.75–12.10) | 18.34 (18.01–18.67) | 17.38 (17.01–17.74) | 13.91 (13.20–14.63) |
| Age-adjusted[c],% (95% CI) | 7.59 (7.26–8.03) | | 11.27 (11.16–11.38) | 19.93 (18.69–19.25) | 19.85 (19.42–20.17) | 14.02 (13.59–14.65) |
| Fully-adjusted [d],% (95% CI) | 9.27 (8.71–10.01) | | 12.17 (12.05–12.28) | 16.81 (16.59–17.25) | 17.41 (17.18–17.65) | 13.98 (13.51–14.23) |
| **Using waist-to-hip ratio indicator** | | | | | | |
| Prevalence of **Non-obese** T2D[e] | | | | | | |
| Crude, % (95% CI) | 2.41 (2.07–2.76) | | 2.89 (2.80–2.99) | 5.34 (5.15–5.53) | 3.77 (3.59–3.95) | 3.93 (3.53–4.34) |
| Age-adjusted[c],% (95% CI) | 2.92 (2.60–3.14) | | 2.80 (2.72–2.84) | 5.65 (5.48–5.72) | 4.13 (3.91–4.15) | 4.40 (3.82–4.48) |
| Fully-adjusted[d],% (95% CI) | 3.14 (3.01–3.36) | | 2.91 (2.89–2.92) | 5.37 (5.15–5.59) | 3.80 (3.74–3.92) | 4.03 (3.80–4.15) |
| Prevalence of **Obese** T2D[e] | | | | | | |
| Crude, % (95% CI) | 9.13 (8.49–9.78) | | 12.35 (12.17–12.52) | 17.80 (17.48–18.13) | 19.14 (18.77–19.52) | 15.02 (14.28–15.76) |
| Age-adjusted[c],% (95% CI) | 12.16 (11.30–12.61) | | 11.46 (11.41–11.51) | 18.38 (18.07–18.51) | 22.53 (22.10–22.76) | 14.98 (14.51–15.61) |
| Fully-adjusted[d],% (95% CI) | 14.62 (14.13–14.80) | | 12.62 (12.51–12.74) | 16.26 (15.92–16.49) | 19.41 (19.32–19.84) | 14.75 (14.03–15.22) |

Abbreviations: T2D, type 2 diabetes; BMI, body mass index; Other race and ethnicity includes American Indian/Alaska Native (824), Middle Eastern or North African (2,771), Native Hawaiian or Pacific Islander (662), those selecting "None of these describe me," (2549) and those who preferred not to answer (3,680).

[a] General cutoffs were categorized as non-obese (normal-weight [BMI <25 kg/m2], overweight [25 ≤ BMI<30 kg/m2], waist circumference <102 cm for males and <88 cm for females; waist-to-hip ratio <0.85 for males and <0.9 for females) and obese (BMI ≥30.0 kg/m2; waist circumference ≥102 cm for males and ≥88 cm for females; waist-to-hip ratio ≥0.85 for males and ≥0.9 for females).

[b] Ethnicity-specific cutoffs were categorized as non-obese (normal-weight [BMI <23 kg/m2], overweight [23 ≤ BMI<27.5 kg/m2]) and obese (BMI ≥27.5 kg/m2).

[c] Age-adjusted (age-and sex-adjusted for BMI) prevalence was controlled for age (sex at birth for BMI) covariates and calculated by using marginal standardization of predicted probabilities from multivariable logistic regression models.

[d] Fully-adjusted prevalence was controlled for age, sex (for BMI only), income, education level and deprivation index and calculated by using marginal standardization of predicted probabilities from multivariable logistic regression models.

[e] Type 2 diabetes was determined by International Classification of Diseases-9/10 codes.

**Table 3**
The proportion of non-obese diabetes among all of us participants with type 2 diabetes using different anthropometric measurements.

| | Asian | | White[a] | Black[a] | Hispanic[a] | Others[a] |
|---|---|---|---|---|---|---|
| | General cutoff[a] | Ethnicity-specific cutoff[b] | | | | |
| **Using BMI indicator** | | | | | | |
| Proportion of **Normal-weight** T2D | | | | | | |
| Crude, % (95% CI) | 29.96 (27.08–32.74) | 15.85 (13.59–18.11) | 11.84 (11.42–12.26) | 11.86 (11.31–12.41) | 10.66 (10.08–11.25) | 13.45 (11.91–14.94) |
| Age-and sex-adjusted e[c], % (95% CI) | 29.65 (27.06–31.81) | 15.64 (14.42–16.25) | 11.47 (10.97–11.71) | 12.45 (12.11–13.08) | 11.00 (10.50–11.43) | 13.23 (12.07–13.54) |
| Fully-adjusted[d],% (95% CI) | 28.53 (26.38–29.27) | 14.98 (13.92–15.86) | 12.30 (12.04–12.79) | 11.91 (11.78–12.43) | 10.00 (9.53–10.21) | 12.90 (12.15–13.75) |
| Proportion of **Overweight** T2D | | | | | | |
| Crude, % (95% CI) | 33.95 (33.22–39.11) | 33.75 (30.77–36.62) | 25.47 (24.90–26.03) | 21.31 (20.62–22.01) | 28.10 (27.25–28.96) | 27.34 (25.39–29.30) |
| Age-and sex-adjusted[c],% (95% CI) | 35.04 (32.31–36.81) | 33.82 (31.92–36.67) | 23.72 (23.57–24.04) | 22.90 (22.47–23.35) | 30.05 (29.76–31.13) | 26.80 (25.54–28.72) |
| Fully-adjusted[d],% (95% CI) | 33.97 (31.23–36.45) | 32.35 (29.94–34.84) | 23.90 (23.18–24.16) | 23.56 (23.15–23.91) | 29.00 (28.50–29.75) | 26.80 (25.36–27.64) |
| Proportion of **Obese** T2D | | | | | | |
| Crude, % (95% CI) | 35.19 (32.24–38.15) | 50.40 (47.35–53.54) | 62.69 (62.07–63.32) | 66.83 (66.02–67.63) | 61.24 (60.31–62.16) | 59.21 (57.05–61.36) |
| Age-and sex-adjusted[c],% (95% CI) | 35.31 (33.67–37.58) | 50.54 (49.65–52.56) | 64.81 (64.48–65.36) | 64.74 (64.31–65.43) | 58.95 (58.06–59.30) | 60.06 (59.05–61.12) |
| Fully-adjusted[d],% (95% CI) | 37.56 (34.86–38.87) | 52.67 (51.15–54.23) | 63.80 (63.81–64.66) | 64.62 (64.26–65.35) | 61.00 (60.72–62.13) | 60.30 (57.75–61.75) |
| **Using waist circumference indicator** | | | | | | |
| Proportion of **Non-obese** T2D | | | | | | |
| Crude, % (95% CI) | 49.57 (46.69–53.31) | | 21.82 (21.25–22.39) | 20.79 (20.07–21.51) | 24.16 (23.30–25.03) | 26.59 (24.50–28.69) |
| Age-adjusted[c],% (95% CI) | 48.48 (46.03–49.92) | | 20.41 (20.26–20.95) | 22.47 (21.82–23.14) | 25.56 (25.35–26.24) | 25.54 (24.53–26.71) |
| Fully-adjusted[d],% (95% CI) | 46.34 (42.51–50.41) | | 20.86 (20.41–21.69) | 22.71 (22.43–23.37) | 24.00 (23.35–24.12) | 25.32 (23.62–26.65) |
| Proportion of **Obese** T2D | | | | | | |
| Crude, % (95% CI) | 50.43 (46.95–53.43) | | 78.18 (77.61–78.75) | 79.21 (78.49–79.93) | 75.84 (74.97–76.70) | 73.41 (71.31–75.50) |
| Age-adjusted[c],% (95% CI) | 51.52 (48.74–53.28) | | 79.59 (79.25–80.01) | 77.53 (76.91–78.27) | 74.44 (73.68–75.12) | 74.46 (72.56–75.52) |
| Fully-adjusted[d],% (95% CI) | 53.76 (50.07–55.23) | | 79.14 (78.67–79.48) | 77.29 (76.87–77.47) | 76.00 (75.31–76.74) | 74.68 (72.89–75.68) |
| **Using waist-to-hip ratio indicator** | | | | | | |
| Proportion of **Non-obese** T2D | | | | | | |
| Crude, % (95% CI) | 20.89 (18.20–23.58) | | 18.99 (18.45–19.54) | 23.08 (22.23–23.83) | 16.45 (15.71–17.20) | 20.76 (18.84–22.68) |
| Age-adjusted[c],% (95% CI) | 19.12 (17.35–21.44) | | 19.05 (18.46–19.67) | 22.98 (21.02–23.7) | 16.58 (16.25–16.91) | 21.79 (19.02–22.56) |
| Fully-adjusted[d],% (95% CI) | 18.31 (16.73–20.14) | | 19.00 (18.37–19.35) | 22.90 (22.53–23.36) | 16.79 (16.53–17.54) | 20.12 (19.62–22.27) |
| Proportion of **Obese** T2D | | | | | | |
| Crude, % (95% CI) | 79.11 (76.42–81.80) | | 81.01 (80.46–81.55) | 76.92 (76.17–77.67) | 83.55 (82.80–84.29) | 79.24 (77.32–81.16) |
| Age-adjusted[c],% (95% CI) | 79.88 (76.8–82.3) | | 80.95 (80.35–81.55) | 77.02 (76.29–77.74) | 83.42 (82.52–84.21) | 78.21 (77.2–80.0) |
| Fully-adjusted[d],% (95% CI) | 81.49 (78.62–82.32) | | 81.00 (80.84–81.41) | 77.10 (76.34–77.31) | 83.21 (83.07–84.07) | 79.29 (77.63–80.81) |

Abbreviations: T2D, type 2 diabetes; BMI, body mass index. Other race and ethnicity includes American Indian/Alaska Native (824), Middle Eastern or North African (2,771), Native Hawaiian or Pacific Islander (662), those selecting "None of these describe me," (2549) and those who preferred not to answer (3,680).

#Type 2 diabetes was determined by International Classification of Diseases 9/10 codes.

[a] General cutoffs were categorized as non-obese (normal-weight [BMI <25 kg/m2], overweight [25 ≤ BMI<30 kg/m2], waist circumference <102 cm for males and <88 cm for females; waist-to-hip ratio <0.85 for males and <0.9 for females) and obese (BMI ≥30.0 kg/m2; waist circumference ≥102 cm for males and ≥88 cm for females; waist-to-hip ratio ≥0.85 for males and ≥0.9 for females).

[b] Ethnicity-specific cutoffs were categorized as non-obese (normal-weight [BMI <23 kg/m2], overweight [23 ≤ BMI<27.5 kg/m2]) and obese (BMI ≥27.5 kg/m2).

[c] Age-adjusted (age-and sex-adjusted for BMI) prevalence was controlled for age (sex at birth for BMI) covariates and calculated by using marginal standardization of predicted probabilities from multivariable logistic regression models.

[d] Fully-adjusted prevalence was controlled for age, sex (for BMI only), income, education level and deprivation index and calculated by using marginal standardization of predicted probabilities from multivariable logistic regression models.

**Table 4**
Association of race and ethnicity with non-obese T2D among all of us participants.

| Odds Ratio | Race | | | | | |
|---|---|---|---|---|---|---|
| | White[a] | Asian | | Black[a] | Hispanic[a] | Other[a] |
| | | General cutoff[a] | Ethnicity-specific cutoff[b] | | | |
| **Non-obese T2D among overall participants[c d]** | | | | | | |
| **Using BMI** | | | | | | |
| Normal-weight, (95% CI) | Ref | 2.77*** (2.44–3.14) | 1.44*** (1.22–1.69) | 1.30*** (1.21–1.40) | 1.24*** (1.14–1.35) | 1.28*** (1.12–1.46) |
| Overweight | Ref | 1.80*** (1.61–2.01) | 1.66*** (1.49–1.87) | 1.32*** (1.25–1.40) | 1.95*** (1.84–2.06) | 1.38*** (1.26–1.52) |
| **Using waist circumference** | | | | | | |
| Non-obese | Ref | 2.61*** (2.35–2.89) | | 1.43*** (1.35–1.52) | 1.83*** (1.71–1.95) | 1.42*** (1.29–1.58) |
| **Using waist-to-hip ratio** | | | | | | |
| Non-obese | ref | 2.61*** (2.35–2.89) | | 1.43*** (1.35–1.52) | 1.83*** (1.71–1.95) | 1.42*** (1.29–1.58) |
| **Non-obese T2D among patients with T2D[c d]** | | | | | | |
| **Using BMI** | | | | | | |
| Normal-weight | ref | 2.85*** (2.47–3.29) | 1.26** (1.06–1.51) | 0.97 (0.90–1.04) | 0.79*** (0.73–0.87) | 1.05 (0.92–1.21) |
| Overweight | ref | 1.71*** (1.49–1.95) | 1.53*** (1.33–1.75) | 0.98 (0.93–1.04) | 1.32*** (1.24–1.41) | 1.20** (1.08–1.33) |
| **Using waist circumference** | | | | | | |
| Non-obese | ref | 3.52*** (3.05–4.07) | | 1.11** (1.04–1.19) | 1.20*** (1.11–1.29) | 1.27*** (1.13–1.43) |
| **Using waist-to-hip ratio** | | | | | | |
| Non-obese | Ref | 0.97 (0.81–1.15) | | 1.27*** (1.19–1.35) | 0.84*** (0.78–0.91) | 1.12 (0.99–1.28) |

*** P-value <0.001; ** P-value <0.01; [a] P-value <0.05.

Abbreviations: T2D, type 2 diabetes; BMI, body mass index. Other race and ethnicity includes American Indian/Alaska Native, Middle Eastern or North.

[a] General cutoffs were categorized as non-obese (normal-weight [BMI <25 kg/m2], overweight [25 ≤ BMI<30 kg/m2], waist circumference <102 cm for males and <88 cm for females; waist-to-hip ratio <0.85 for males and <0.9 for females) and obese (BMI ≥30.0 kg/m2; waist circumference ≥102 cm for males and ≥88 cm for females; waist-to-hip ratio ≥0.85 for males and ≥0.9 for females).

[b] Ethnicity-specific cutoffs were categorized as non-obese (normal-weight [BMI <23 kg/m2], overweight [23 ≤ BMI<27.5 kg/m2]) and obese (BMI ≥27.5 kg/m2).

[c] Odds ratios were calculated using multivariate logistic regression models adjusted for age, sex (for BMI only), income, education level, and deprivation index.

[d] Type 2 diabetes was determined by International Classification of Diseases 9/10 codes.

White individuals (Karnes et al., 2021).

Genetic factors may in part explain the higher non-obese T2D prevalence among Asian American individuals when using BMI. BMI has been found to be sensitive to genetic influences (Silventoinen et al., 2016) and studies have discovered several genetic loci that increased diabetes risks in Chinese (Hu and Jia, 2017) and Indian (Radha and Mohan, 2007) population, along with a higher insulin sensitivity among them. Research using data from Luzon Island in the Philippines identified strong association between polymorphisms in genes and susceptibility to diabetes (Bugawan et al., 2003). While Chinese, Filipino, and Indian ancestries comprise some of the largest ethnic groups within the Asian American population (Census, 2023), it is important to consider that the Asian American community is highly diverse, and more research is needed to understand how genetic factors might impact diabetes risk across various Asian American ethnic subgroups. The higher proportion of non-obese individuals among T2D patients for Asian adults also provides supportive evidence that genetic influence might contribute to the increases in non-obese T2D among this group.

Our findings on waist circumference displayed that only Asian American adults had significantly higher prevalence and proportion of non-obese T2D. Beyond the genetic factors that increase the diabetes risk among Asian individuals, they might carry greater abdominal and visceral fat with lower waist circumference compared to the entire cohort (Lim et al., 2011). Meanwhile, the disparities in non-obese diabetes prevalence and proportion among Asian American adults suggest lower optimal waist circumference cut points than other racial and ethnic groups (Zeng et al., 2014; Park et al., 2009). Current waist circumference measures might overestimate central adiposity in Asian Americans. Unlike BMI, there are no clear ethnicity-specific waist circumference cutoffs for Asian Americans. Future studies should focus on establishing such cutoffs for ethnic subgroups among and within Asian population in the US.

For Black adults, the waist-to-hip ratio emerged as a sensitive indicator of non-obese T2D risk, reflecting their unique fat distribution patterns. Although Black adults had the highest BMI, waist circumference and hip circumference among racial and ethnic groups in this study, they displayed the highest non-obese T2D prevalence and proportion only using waist-to-hip ratio. This apparent paradox may be explained by the tendency of Black individuals to have more subcutaneous fat deposited in the hips and thighs rather than in abdominal areas (Tchernof and Després, 2013). This fat distribution pattern results in a more “pear-shaped” body type, where greater hip circumference lowers the waist-to-hip ratio despite higher overall adiposity. Consequently, measurements using BMI and waist circumference alone may not fully capture the central adiposity associated with T2D risk in this group, potentially leading to

underestimation of prevalence. Studies using data from the Women's Health Initiative have shown that waist-to-hip ratio correlates strongly with trunk-to-leg fat ratio, a marker for "pear-shaped" body shape. This correlation suggests that waist-to-hip ratio may be a more accurate anthropometric measurement for assessing diabetes risk among Black adults. These findings underscore the importance of considering multiple anthropometric measures, particularly waist-to-hip ratio, when evaluating T2D risk in Black populations (Luo et al., 2018).

There are several limitations to this study. First, although use of the EHR is a strength in some respects, the missingness in physical measurements (e.g., BMI, waist circumference) and ICD code–defined T2D definitions may lead to ascertainment bias (with misclassification). The lack of comprehensive body composition indices (such as body fat percentage and visceral fat area) in the AoU database could affect both our assessment of adiposity. Future studies incorporating these more precise measurements of adiposity distribution would further enhance our understanding in non-obese T2D risk among different groups. Meanwhile, the potential inaccuracies in T2D diagnosis using ICD codes alone could affect our assessment of the prevalence of non-obese T2D. Future validation studies comparing ICD code-based diagnoses with clinical documentation, laboratory values, and medication data would help establish the accuracy of our T2D identification method. Second, AoU research program did not employ corresponding weighting methods as AoU used purposeful sampling instead of being nationally representative. Thus, the result might not represent the broader US population, especially given the low percentage of rural populations in the database (Graves et al.). Future study could focus on addressing this limitation by comparing AoU dataset with other population studies (e.g., NHANES). Lastly, as our study population is enriched in underserved and disadvantaged persons, results may differ compared to results from health claims data from insured individuals, and an underrepresentation of Asian Americans born outside the US, or with lower education and literacy levels (Randal et al., 2023).

In conclusion, we demonstrated significant racial and ethnic differences in the non-obese T2D prevalence among US adults and non-obese proportion among patients with T2D by using BMI, waist circumference, and waist-to-hip ratio as indicators. The varied non-obese T2D prevalence observed using different anthropometric measures highlights the need for developing ethnicity-specific cutoffs for obesity indicators. These results underscore the importance of considering multiple anthropometric measures when assessing T2D risk across racial and ethnic groups. They also emphasize the need for a more nuanced approach to obesity classification that accounts for racial and ethnic differences in body composition and fat distribution in future research.

## CRediT authorship contribution statement

**Junyu Sui:** Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Bei Wu:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Formal analysis. **Yaguang Zheng:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Zhiyue Mo:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Qianyu Dong:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Lan N. Đoàn:** Writing – review & editing, Writing – original draft, Methodology. **Stella S. Yi:** Writing – review & editing, Writing – original draft, Methodology. **Xiang Qi:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization.

## Statement of ethics

The All of Us institutional review board approved all study procedures. Participants have given informed consent upon joining the All of Us program, including consent to access their EHR information. We performed all analyses in accordance with the All of Us Code of Conduct.

## Data availability statement

Data will be available to investigators with control tier access through All of Us Research Workbench (researchallofus.org). Access to the data used in this study is restricted due to patients' privacy concerns and compliance with the National Institutes of Health's All of Us Research Program. The All of Us Research Program is responsible for maintaining and storing this data, which is not publicly accessible.

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Appendix

**Appendix Table 1**
ICD-9-CM and ICD-10-CM diagnosis codes for type 2 diabetes and related complications.

| ICD Version | Code Range | Description |
|---|---|---|
| ICD-9-CM | 250.00 | Diabetes mellitus without mention of complication, type II or unspecified type, not stated as uncontrolled |
| ICD-9-CM | 250.02 | Diabetes mellitus without mention of complication, type II or unspecified type, uncontrolled |
| ICD-9-CM | 250.60 | Diabetes with neurological manifestations, type II or unspecified type, not stated as uncontrolled |
| ICD-10-CM | E11.21 | Type 2 diabetes mellitus with diabetic nephropathy |
| ICD-10-CM | E11.29 | Diabetes with peripheral circulatory disorders, type II or unspecified type, not stated as uncontrolled |
| ICD-9-CM | 250.72 | Diabetes with peripheral circulatory disorders, type II or unspecified type, uncontrolled |
| ICD-10-CM | E11.9 | Type 2 diabetes mellitus without complications |
| ICD-10-CM | E11.40 | Type 2 diabetes mellitus with diabetic neuropathy, unspecified |
| ICD-10-CM | E11.628 | Type 2 diabetes mellitus with unspecified complications |
| ICD-9-CM | 250.40 | Diabetes with renal manifestations, type II or unspecified type, not stated as uncontrolled |
| ICD-9-CM | 250.52 | Diabetes with ophthalmic manifestations, type II or unspecified type, uncontrolled |
| ICD-10-CM | E11.39 | Type 2 diabetes mellitus with other diabetic ophthalmic complication |
| ICD-10-CM | E11.22 | Type 2 diabetes mellitus with diabetic chronic kidney disease |
| ICD-10-CM | E11.33 | Type 2 diabetes mellitus with moderate nonproliferative diabetic retinopathy |
| ICD-9-CM | 250.22 | Diabetes with hyperosmolarity, type II or unspecified type, uncontrolled |
| ICD-10-CM | E11.641 | Type 2 diabetes mellitus with hypoglycemia with coma |
| ICD-10-CM | E11.65 | Type 2 diabetes mellitus with hyperglycemia |
| ICD-9-CM | 250.80 | Diabetes with other specified manifestations, type II or unspecified type, not stated as uncontrolled |
| ICD-9-CM | 250.90 | Diabetes with unspecified complication, type II or unspecified type, not stated as uncontrolled |
| ICD-9-CM | 250.30 | Diabetes with other coma, type II or unspecified type, not stated as uncontrolled |
| ICD-10-CM | E11.00 | Type 2 diabetes mellitus with hyperosmolarity without nonketotic hyperglycemic-hyperosmolar coma (NKHHC) |
| ICD-9-CM | 250.20 | Diabetes with hyperosmolarity, type II or unspecified type, not stated as uncontrolled |
| ICD-10-CM | E11.618 | Type 2 diabetes mellitus with other diabetic arthropathy |
| ICD-9-CM | 250.32 | Diabetes with other coma, type II or unspecified type, uncontrolled |
| ICD-10-CM | E11.69 | Type 2 diabetes mellitus with other specified complication |
| ICD-10-CM | E11.51 | Type 2 diabetes mellitus with diabetic peripheral angiopathy without gangrene |
| ICD-10-CM | E11.649 | Type 2 diabetes mellitus with hypoglycemia without coma |
| ICD-9-CM | 250.50 | Diabetes with ophthalmic manifestations, type II or unspecified type, not stated as uncontrolled |
| ICD-10-CM | E11.319 | Type 2 diabetes mellitus with unspecified diabetic retinopathy without macular edema |
| ICD-9-CM | 250.62 | Diabetes with neurological manifestations, type II or unspecified type, uncontrolled |
| ICD-9-CM | 250.42 | Diabetes with renal manifestations, type II or unspecified type, uncontrolled |
| ICD-10-CM | E11.36 | Type 2 diabetes mellitus with diabetic cataract |
| ICD-10-CM | E11.311 | Type 2 diabetes mellitus with unspecified diabetic retinopathy with macular edema |
| ICD-10-CM | E11.321 | Type 2 diabetes mellitus with mild nonproliferative diabetic |
| ICD-10-CM | E11.630 | Type 2 diabetes mellitus with periodontal disease |
| ICD-10-CM | E11.638 | Type 2 diabetes mellitus with other oral complications |
| ICD-10-CM | E11.621 | Type 2 diabetes mellitus with foot ulcer |
| ICD-10-CM | E11.622 | Type 2 diabetes mellitus with other skin ulcer |
| ICD-9-CM | 250.92 | Diabetes with unspecified complication, type II or unspecified type, uncontrolled |
| ICD-10-CM | E11.01 | Type 2 diabetes mellitus with hyperosmolarity with coma |
| ICD-10-CM | E11.620 | Type 2 diabetes mellitus with diabetic dermatitis |
| ICD-10-CM | E11.1 | Type 2 diabetes mellitus with ketoacidosis |
| ICD-10-CM | E11.341 | Type 2 diabetes mellitus with severe nonproliferative diabetic retinopathy with macular edema |

**Appendix Table 2**
Anthropometric measurements by race/ethnicity and sex at birth using second-level subgroups of waist circumference and waist-to-hip ratio measurement under the normal BMI category.

| | Sex | Asian† | White* | Black* | Hispanic* | Others* |
|---|---|---|---|---|---|---|
| Waist circumference (cm) | Female | 69.42 (65.63–73.48) | 71.42 (68.00–75.15) | 71.50 (67.50–75.40) | 70.71 (67.00–74.20) | 70.93 (67.30–74.90) |
| | Male | 76.24 (72.40–80.45) | 79.14 (75.36–83.31) | 77.57 (73.70–81.50) | 77.10 (73.35–81.18) | 78.18 (74.00–82.20) |
| Waist-to-hip ratio | Female | 0.768 (0.73–0.80) | 0.76 (0.73–0.80) | 0.78 (0.75–0.82) | 0.77 (0.74–0.81) | 0.77 (0.74–0.80) |
| | Male | 0.821 (0.79–0.86) | 0.84 (0.81–0.87) | 0.83 (0.81–0.87) | 0.84 (0.81–0.87) | 0.83 (0.81–0.87) |

* General BMI category was categorized as BMI <25 kg/m2.
† Asian ethnicity-specific BMI category was categorized as BMI <23 kg/m2.

**Appendix Table 3**
The prevalence of type 2 diabetes among All of Us participants using second-level subgroups of waist circumference and waist-to-hip ratio measurement under the normal BMI category.

| | Asian | White | Black | Hispanic | Others |
|---|---|---|---|---|---|
| Under normal BMI and waist circumference category* | | | | | |

(*continued on next page*)

**Appendix Table 3** (*continued*)

| | Asian | White | Black | Hispanic | Others |
|---|---|---|---|---|---|
| Prevalence of T2D# | | | | | |
| Crude, % (95% CI) | 1.60 (1.32–1.88) | 0.79 (0.75–0.84) | 1.34 (1.25–1.44) | 0.98 (0.89–1.08) | 1.07 (0.85–1.28) |
| Age-and sex-adjusted‡,% (95% CI) | 2.08 (1.73–2.35) | 0.75 (0.70–0.81) | 1.40 (1.32–1.51) | 1.21 (1.02–1.38) | 1.05 (0.89–1.13) |
| Fully-adjusted§,% (95% CI) | 2.40 (1.95–2.81) | 0.93 (0.91–0.94) | 1.14 (1.17–1.21) | 0.91 (0.83–0.97) | 1.22 (1.05–1.34) |
| **Under normal BMI and waist-to-hip ratio category†** | | | | | |
| Prevalence of T2D # | | | | | |
| Crude, % (95% CI) | 0.83 (0.63–1.04) | 0.48 (0.44–0.52) | 0.71 (0.63–0.77) | 0.42 (0.36–0.48) | 0.57 (0.41–0.72) |
| Age-adjusted‡,% (95% CI) | 1.04 (0.73–1.13) | 0.52 (0.43–0.51) | 0.75 (0.71–0.82) | 0.52 (0.49–0.56) | 0.61 (0.48–0.65) |
| Fully-adjusted§,% (95% CI) | 1.14 (0.88–1.39) | 0.56 (0.53–0.57) | 0.68 (0.65–0.71) | 0.48 (0.46–0.49) | 0.57 (0.53–0.59) |

Abbreviations: T2D, type 2 diabetes; BMI, body mass index; Other race and ethnicity include American Indian/Alaska Native (824), Middle Eastern or North African (2,771), Native Hawaiian or Pacific Islander (662), those selecting "None of these describe me," (2549) and those who preferred not to answer (3,680).

* Cutoffs were categorized as: BMI <25 kg/m2; waist circumference <102 cm for males and <88 cm for females. For Asian adults, BMI was adjusted as <23 kg/m2.

† Cutoffs were categorized as: BMI <25 kg/m2, waist-to-hip ratio <0.85 for males and <0.9 for females. For Asian adults, BMI was adjusted as <23 kg/m2.

‡ Age-adjusted prevalence was controlled for age covariates and calculated by using marginal standardization of predicted probabilities from multivariable logistic regression models.

§ Fully-adjusted prevalence was controlled for age, income, education level and deprivation index and calculated by using marginal standardization of predicted probabilities from multivariable logistic regression models.

# Type 2 diabetes was determined by International Classification of Diseases-9/10 codes.

**Appendix Table 4**

Prevalence of type 2 diabetes among All of Us participants by obesity phenotype, stratified by race and sex at birth.

| Prevalence | Race and ethnicity | | | | | Sex at birth | |
|---|---|---|---|---|---|---|---|
| | Asian† | White* | Black* | Hispanic* | Others* | Male | Female |
| **Normal BMI, waist circumference, and waist-to-hip ratio** | | | | | | | |
| Crude, % (95% CI) | 0.84 (0.64–1.05) | 0.77 (0.73–0.82) | 1.11 (1.02–1.20) | 0.69 (0.61–0.77) | 1.01 (0.80–1.22) | 0.87 (0.81–0.93) | 0.83 (0.78–0.87) |
| Age-adjusted‡,% (95% CI) | 1.08 (0.93–1.25) | 0.76 (0.72–0.79) | 1.21 (1.12–1.28) | 0.81 (0.72–0.88) | 1.03 (0.98–1.09) | 0.88 (0.85–0.95) | 0.84 (0.81–0.94) |
| Fully-adjusted§,% (95% CI) | 1.04 (0.75–1.21) | 0.85 (0.81–0.89) | 1.04 (0.97–1.11) | 0.78 (0.73–0.85) | 1.02 (0.95–1.14) | 0.86 (0.82–0.91) | 0.89 (0.83–0.94) |
| **High BMI, normal waist circumference** | | | | | | | |
| Crude, % (95% CI) | 4.15 (3.70–4.60) | 1.82 (1.75–1.89) | 2.53 (2.39–2.66) | 3.61 (3.43–3.79) | 2.85 (2.51–3.19) | 4.33 (4.20–4.46) | 1.15 (1.10–1.21) |
| Age- adjusted‡,% (95% CI) | 5.41 (4.84–5.74) | 1.74 (1.63–1.84) | 2.65 (2.59–2.73) | 4.67 (4.52–4.79) | 2.72 (2.52–2.93) | 4.37 (4.32–4.43) | 1.22 (1.15–1.26) |
| Fully-adjusted§,% (95% CI) | 5.75 (5.14–6.45) | 1.79 (1.72–1.82) | 2.67 (2.53–2.88) | 4.04 (3.94–4.26) | 2.78 (2.57–2.96) | 4.35 (4.31–4.44) | 1.20 (1.12–1.25) |
| **High BMI, normal waist-to-hip ratio** | | | | | | | |
| Crude, % (95% CI) | 0.49 (0.33–0.64) | 1.50 (1.43–1.56) | 3.41 (2.99–3.29) | 2.02 (1.89–2.16) | 1.97 (1.69–2.26) | 0.38 (0.34–0.42) | 2.92 (2.83–3.00) |
| Age-adjusted‡,% (95% CI) | 0.60 (0.43–0.77) | 1.47 (1.43–1.51) | 3.35 (3.31–3.42) | 2.18 (2.09–2.33) | 2.19 (1.98–2.36) | 0.43 (0.41–0.47) | 2.94 (2.91–3.03) |
| Fully-adjusted §, % (95% CI) | 0.74 (0.58–1.03) | 1.52 (1.45–1.57) | 3.18 (2.95–3.27) | 2.08 (1.96–2.19) | 2.07 (1.93–2.25) | 0.46 (0.43–0.49) | 2.97 (2.94–3.02) |
| **Normal BMI, high waist circumference** | | | | | | | |
| Crude, % (95% CI) | 0.11 (0.03–0.18) | 0.26 (0.24–0.29) | 0.40 (0.34–0.45) | 0.38 (0.32–0.44) | 0.26 (0.15–0.36) | 0.12 (0.10–0.14) | 0.43 (0.39–0.46) |
| Age-adjusted‡,% (95% CI) | 0.21 (0.16–0.26) | 0.27 (0.24–0.29) | 0.56 (0.48–0.59) | 0.51 (0.48–0.53) | 0.34 (0.22–0.43) | 0.14 (0.13–0.16) | 0.46 (0.42–0.53) |
| Fully-adjusted e§, % (95% CI) | 0.24 (0.14–0.35) | 0.35 (0.29–0.38) | 0.43 (0.37–0.48) | 0.48 (0.35–0.54) | 0.36 (0.28–0.39) | 0.15 (0.12–0.18) | 0.48 (0.44–0.52) |
| **Normal BMI, high waist-to-hip ratio** | | | | | | | |
| Crude, % (95% CI) | 0.77 (0.58–0.97) | 0.71 (0.67–0.76) | 1.19 (1.10–1.28) | 1.24 (1.13–1.34) | 1.13 (0.91–1.35) | 1.47 (1.39–1.54) | 0.58 (0.54–0.62) |
| Age-adjusted‡,% (95% CI) | 1.05 (0.86–1.23) | 0.67 (0.62–0.71) | 1.32 (1.26–1.37) | 1.65 (1.52–1.77) | 1.12 (0.96–1.24) | 1.45 (1.40–1.53) | 0.62 (0.55–0.67) |
| Fully-adjusted §, % (95% CI) | 1.31 (1.07–1.48) | 0.87 (0.75–0.83) | 1.07 (1.02–1.14) | 1.21 (1.18–1.25) | 1.08 (0.95–1.23) | 1.42 (1.38–1.53) | 0.66 (0.58–0.69) |
| **High BMI, waist circumference, and waist-to-hip ratio** | | | | | | | |

(*continued on next page*)

**Appendix Table 4** (*continued*)

| Prevalence | Race and ethnicity | | | | | Sex at birth | |
|---|---|---|---|---|---|---|---|
| | Asian† | White* | Black* | Hispanic* | Others* | Male | Female |
| Crude, % (95% CI) | 5.11 (4.61–5.60) | 10.11 (9.95–10.28) | 14.81 (14.51–15.11) | 14.99 (14.64–15.33) | 11.72 (11.06–12.38) | 12.37 (12.16–12.58) | 11.54 (11.38–11.71) |
| Age-adjusted‡,% (95% CI) | 6.72 (6.31–0.75) | 9.54 (9.48–9.59) | 15.24 (15.02–15.39) | 17.34 (16.92–17.65) | 11.74 (11.12–11.95) | 12.15 (11.94–12.13) | 11.70 (11.62–11.87) |
| Fully-adjusted §, % (95% CI) | 8.43 (7.51–8.64) | 10.39 (10.28–10.47) | 13.45 (13.22–13.74) | 15.12 (14.83–15.56) | 11.65 (11.09–11.76) | 12.25 (12.14–12.35) | 11.73 (11.54–11.79) |

Abbreviations: T2D, type 2 diabetes; BMI, body mass index; Other race and ethnicity include American Indian/Alaska Native (824), Middle Eastern or North African (2,771), Native Hawaiian or Pacific Islander (662), those selecting "None of these describe me," (2549) and those who preferred not to answer (3,680).

* General cutoffs were categorized as non-obese (normal-weight [BMI <25 kg/m2], overweight [25 ≤ BMI<30 kg/m2], waist circumference <102 cm for males and <88 cm for females; waist-to-hip ratio <0.85 for males and <0.9 for females) and obese (BMI ≥30.0 kg/m2; waist circumference ≥102 cm for males and ≥88 cm for females; waist-to-hip ratio ≥0.85 for males and ≥0.9 for females).

† Ethnicity-specific cutoffs were categorized as non-obese (normal-weight [BMI <23 kg/m2], overweight [23 ≤ BMI<27.5 kg/m2]) and obese (BMI ≥27.5 kg/m2).

‡ Age-adjusted (age-and sex-adjusted for BMI) prevalence was controlled for age (sex at birth for BMI) covariates and calculated using marginal standardization of predicted probabilities from multivariable logistic regression models.

§ Fully-adjusted prevalence was controlled for age, sex (for BMI only), income, education level, and deprivation index and calculated using marginal standardization of predicted probabilities from multivariable logistic regression models.

# Type 2 diabetes was determined by International Classification of Diseases-9/10 codes.

**Appendix Table 5**

Odds ratios of different obesity phenotype with type 2 diabetes among All of Us Participants

| Phenotype | Odds ratio‡ | 95% CI |
|---|---|---|
| Normal BMI*†, waist circumference* and waist-to-hip ratio* | ref | |
| High BMI, normal waist circumference | 2.10*** | (1.99–2.21) |
| Normal BMI, high waist-to-hip ratio | 2.23*** | (2.09–2.38) |
| Normal BMI, high waist circumference | 3.38*** | (3.08–3.72) |
| High BMI, normal waist-to-hip ratio | 3.70*** | (3.50–3.92) |
| High BMI, waist circumference and waist-to-hip ratio | 6.32*** | (6.02–6.63) |

*** P-value <0.001; ** P-value <0.01; * P-value <0.05.

Abbreviations: T2D, type 2 diabetes; BMI, body mass index.

* General cutoffs were categorized as non-obese (BMI <30 kg/m2; waist circumference <102 cm for males and <88 cm for females; waist-to-hip ratio <0.85 for males and <0.9 for females) and obese (BMI ≥30.0 kg/m2; waist circumference ≥102 cm for males and ≥88 cm for females; waist-to-hip ratio ≥0.85 for males and ≥0.9 for females).

† Asian ethnicity-specific cutoffs were categorized as non-obese (BMI <27.5 kg/m2) and obese (BMI ≥27.5 kg/m2).

‡ Odds ratios were calculated using multivariate logistic regression models adjusted for age, income, education level, and deprivation index.

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