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ORIGINAL ARTICLE

Anthropometric discriminators of type 2 diabetes among White and Black American adults

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Abstract

Background: The aim of the present study was to determine the best anthropometric discriminators of type 2 diabetes mellitus (T2DM) among White and Black males and females in a large US sample.

Methods: We used Atherosclerosis Risk in Communities study baseline data (1987–89) from 15 242 participants (1827 with T2DM) aged 45–65 years. Anthropometric measures included a body shape index (ABSI), body adiposity index (BAI), body mass index, waist circumference (WC), waist: height ratio (WHtR), and waist: hip ratio (WHR). All anthropometric measures were standardized to *Z*-scores. Using logistic regression, odds ratios for T2DM were adjusted for age, physical activity, and family history of T2DM. The Akaike information criterion and receiver operating characteristic C-statistic were used to select the best-fit models.

Results: Body mass index, WC, WHtR, and WHR were comparable discriminators of T2DM among White and Black males, and were superior to ABSI and BAI in predicting T2DM ($P < 0.0001$). Waist circumference, WHtR, and WHR were the best discriminators among White females, whereas WHR was the best discriminator among Black females. The ABSI was the poorest discriminator of T2DM for all race–gender groups except Black females. Anthropometric values distinguishing T2DM cases from non-cases were lower for Black than White adults.

Conclusions: Anthropometric measures that included WC, either alone or relative to height (WHtR) or hip circumference (WHR), were the strongest discriminators of T2DM across race–gender groups. Body mass index was a comparable discriminator to WC, WHtR, and WHR among males, but not females.

Keywords: gender, obesity, race, type 2 diabetes.

Significant findings of the study: Body mass index, WC, WHtR, and WHR were comparable anthropometric discriminators of T2DM among White and Black males in the US, whereas WC, WHtR, and WHR were the best discriminators among White females. The WHR was the best discriminator among Black females.

What this study adds: Anthropometric measures that included WC, either alone or relative to height (WHtR) or hip circumference (WHR), were the strongest discriminators of T2DM across race–gender groups. Body mass index was a comparable discriminator to WC, WHtR, and WHR among males, but not females.

Introduction

The prevalence of type 2 diabetes mellitus (T2DM) has more than tripled over the past 30 years, affecting 29.1 million Americans, which represents 9.3 % of the US population.[1] Type 2 diabetes mellitus is a major cause of heart disease and stroke, and is the seventh leading cause of death in the US. It is estimated that over 3.8 million Blacks (13.2 %) aged 20 years or older in the US have diagnosed or undiagnosed T2DM.[1] Several risk factors are associated with T2DM and its complications, including obesity, older age, family history of T2DM, history of gestational diabetes, impaired glucose metabolism, physical inactivity, and certain racial/ethnic origin.[2]

Excess adiposity and the prevalence of obesity have increased significantly among US adults and youths between 1999 and 2004.[3] Visceral adipose tissue and, to a lesser degree, subcutaneous abdominal adipose tissue are hormonally active tissues known to be related to the development of T2DM, metabolic syndrome, and other cardiometabolic abnormalities.[4] The mechanism involves a release of excess fatty acids and inflammatory cytokines into the portal circulation.[5] Visceral adipose tissue volume and the values associated with health risk differ by race and gender.[4,6–9] Whereas visceral adipose tissue volume is greater in White men and women than Black men and women in the US, subcutaneous adipose tissue volume is lower in White men and women compared with Black men and women after adjusting for age, total body fat, smoking, and menopausal status.[8,9] Despite having relatively less visceral adipose tissue and more muscle mass than Whites, Blacks have a higher prevalence of insulin resistance, T2DM, and cardiovascular disease.[4,6]

Anthropometric measures that are considered surrogates for visceral adipose and subcutaneous adipose tissues are used to estimate abdominal obesity and subsequent T2DM disease risk[10–13] and consequential premature mortality.[14] The risk of T2DM increases with general and central obesity and is decreased or prevented with weight loss of 5 %–7 % of body weight.[15] Anthropometric measures are currently being used in medical settings to screen for obesity-associated health risk. The application of cost-effective and efficient anthropometric screening measures to assess T2DM risk may be useful to identify patients who are in greatest need of preventive treatment. In addition, characteristics such as race and gender may determine which anthropometric measurements are most useful to identify individuals at risk of developing T2DM.

Two commonly used anthropometric measures are body mass index (BMI) and waist circumference (WC), both of which have their limitations. Body mass index provides an estimate of general obesity, but does not distinguish between fat and muscle mass, and is a poor discriminator of cardiovascular risk.[16,17] Waist circumference, a measure of central obesity that is highly correlated with BMI,[18] is associated with T2DM in various populations,[11,18–20] has varied cut-off values depending on race and gender,[16,19–21] and may over- or underestimate T2DM risks in short or tall people.[22] Visceral adipose tissue and WC are better discriminators of cardiometabolic risks than BMI, fat mass, and percent body fat.[7] Across levels of WC or BMI, women have higher levels of subcutaneous adipose tissue volume than men.[4] Especially at higher levels of BMI and WC, visceral adipose tissue is greater in White men and women than Black men and women. Consequently, visceral adipose tissue may play a bigger role in predicting cardiometabolic risks in Whites than Blacks.[4,8] At higher levels of BMI, fat mass becomes reduced between Black American men and women, whereas this difference is constant between White men and women.[8]

Other anthropometric measures are waist: hip ratio (WHR), a measure of WC divided by hip circumference, and waist: height ratio (WHtR), computed as WC divided by height.[23] In Mexican Americans, WC is a better discriminator than BMI or WHR when screening for T2DM.[24] Generally, WC, WHR, and WHtR are considered better discriminators of T2DM risk than BMI.[25] Body adiposity index (BAI), calculated using hip circumference and height, has been used as a risk indicator among Mexican Americans and Black Americans.[26] In another study, BMI and BAI were similar at predicting body fat and differed by sex, but only BMI differed by race between Whites and Blacks.[27] However, the disease discrimination and validation of BAI is not known and further research is warranted.

In an effort to address limitations of existing anthropometric measures, Krakauer et al.[28] developed a new measure called A body shape index (ABSI) based on WC, BMI, and height. In their studies,[28,29] ABSI was positively correlated with mortality among males and females and across different age groups of White and Black Americans[28]; ABSI was a better predictor of mortality than WC, WHtR, and WHR over 20 years of follow-up.[29] Other studies report that ABSI is a weaker predictor of cardiovascular disease mortality among White Americans,[30] cardiovascular disease risk factors among Asians,[11,31,32] and stroke risk among Spanish European men.[33] It is not known whether ABSI, BAI, BMI, WC, WHtR, or WHR is the best discriminator of T2DM in White and Black Americans. The aim of the present study was to determine the predictive ability of the anthropometric measures to discriminate T2DM

in a large cross-sectional sample of middle-aged White and Black males and females in the US.

Methods

Study sample of White and Black American adults

The study sample was drawn from the Atherosclerosis Risk in Communities (ARIC) study, a large, ongoing, prospective cohort study designed to investigate the etiology of atherosclerosis and clinical outcomes of approximately 16 000 American adults in four US communities (Baltimore, MD; Minneapolis, MN; Jackson, MI; and Winston-Salem, NC). Each ARIC field center randomly selected and recruited a cohort of approximately 4000 individuals aged 45–64 years from a defined population in their community between 1987 and 1989.

Baseline de-identified ARIC data from 15 242 participants were obtained from BioLINCC (https://biolincc.nhlbi.nih.gov/home/, accessed 4 May 2016). Further design and sampling methods are explained elsewhere.[34,35] All participants provided informed consent. The present secondary data analysis was approved by the Augusta University (formerly Medical College of Georgia) Institutional Review Board.

Study variables

The outcome variable, T2DM, was defined using the American Diabetes Association criteria[36] as the presence of at least one the following: fasting blood glucose (FBG) ≥126 mg/dL, non-FBG ≥200 mg/dL, self-report of diabetes diagnosis, or self-report of taking diabetes medications. The anthropometric measures included ABSI, calculated as WC (m)/[$BMI^{0.66} \times$ height $(m)^{0.5}$]; BAI, calculated as hip circumference (cm)/[(height $(m)^{1.5}$) – 18]; BMI, calculated by dividing body weight (kg) by height (m) squared; WC (cm); WHtR, calculated by dividing WC (cm) by height (cm); and WHR, calculated by dividing WC (cm) by hip circumference (cm). These predictor variables were examined separately in their respective models. Measurements of body weight, height, WC, and hip circumference were performed by two trained ARIC technicians. If there was only one technician, a full-length mirror was used to aid placement of the tape measure. Participants were measured in the fasted state, in light clothing without shoes. Weight was measured using a digital scale (Model #437; Detecto, Webb City, MO, USA) to the nearest 0.5 lb (0.23 kg). Height was measured with a stadiometer; WC was measured using an anthropometric tape at the level of the umbilicus, with the participant standing erect and the position verified using an observer or mirror per standard ARIC protocol;[37] hip circumference was measured horizontally at the greatest level of protrusion of the buttocks. Height, WC, and hip circumference were measured to the nearest cm.

The following participant characteristics were considered for covariate adjustment in multivariate logistic regression analyses: age, gender, physical activity (computed as physical activities at work + sport + leisure using the Baecke physical activity index[38]), and family history of T2DM (yes/no). Additional descriptive characteristics not included in the data models were FBG (mg/dL), high-density lipoprotein cholesterol (mg/dL), use of blood pressure medications (yes/no), ever smoked cigarettes (yes/no), alcohol intake (g/day), and highest education level completed (less than high school, high school graduate to some college or vocational school graduate, and college graduate or higher).

Statistical analysis

Statistical analyses were conducted using Stata MP, Version 14.0 (StataCorp, College Station, TX, USA). Logistic regression was used for the univariate (anthropometric discriminator and T2DM) and bivariate (anthropometric discriminator adjusted for each covariate on T2DM) analyses for males and females. The covariates included age (5-year increments), physical activity (Baecke units), and family history of diabetes (yes/no). Similarly, multivariate associations of each anthropometric measure adjusted for covariates were determined. All anthropometric measures were standardized to Z-scores for each race–gender group using the following equation:

Z-score = (individual anthropometric value – group mean anthropometric value)/group SD.

Participants with missing observations (n = 243) for any variable were excluded in order to have a complete dataset. Several models were explored; the most parsimonious models are presented in order to be able to generalize our findings back to the parent White and Black populations.

The Akaike information criterion (AIC) was used in building the multivariate models. With the stepwise addition of covariates to the model, the AIC values decreased until the smallest AIC was achieved. The receiver operating characteristic (ROC) curve was used to evaluate the results of the AIC. The ROC curves were constructed by regressing each anthropometric measure with age, physical activity, and family history of diabetes on T2DM in separate models, then assessing the fit of the model. The models with the highest ROC concordance statistic (C-statistic) were chosen for each respective anthropometric model in race–gender models. The ROC curves were plotted by using the true positive rate

against the false positive rate for all anthropometric multivariate models for White and Black males and females separately. We further tested the equality of ROC curves by testing whether two or more ROC areas were close in discriminatory ability within race–gender groups by examining the C-statistic and the *P*-value from their respective tests. A C-statistic ≤0.5 indicates no discrimination (i.e. the model is no better than chance for predicting which individuals have T2DM), whereas C-statistic values ≥0.7 and <0.8 are considered to indicate acceptable discrimination, those ≥0.8 and <0.9 are considered to indicate excellent discrimination, and those ≥0.9 are considered to indicate outstanding discrimination.[39] In all analyses, two-tailed $P < 0.05$ was considered significant. The case identifier to distinguish T2DM cases from non-cases for each anthropometric measure was calculated as the point on the ROC curve that is farthest from the line of equality (reference line).[39,40]

Results

Characteristics of the sample of White and Black American adults

Descriptive characteristics for all American participants by race- and gender-specific stratifications are presented in Table 1. The sample included 15 242 participants/1827 T2DM cases (5320/543 White males, 1527/285 Black males, 5936/479 White females, and 2459/520 Black females). The mean ABSI was higher among Whites than Blacks. Mean BMI was higher among Black females than White females (30.8 vs 26.6 kg/m^2, respectively), and BAI and WHtR were highest among Black females than other race–gender groups. Behavioral characteristics revealed that the mean Baecke physical activity scores were lowest for Black males and highest for White males. Black males and females had higher FBG than their White counterparts, which was mirrored in their diagnosis of T2DM.

Table 1 Descriptive characteristics of all American participants by gender and race

		Mean ± SD or percentage of sample			
	Range	Whites males (n = 5320)	Black males (n = 1527)	White females (n = 5936)	Black females (n = 2459)
Age (years)	45–64	54.8 ± 5.7	53.9 ± 6.0*	54.0 ± 5.7	53.3 ± 5.7†
Physical activity[1] (Baecke units)	3–14	7.4 ± 1.4	6.4 ± 1.5*	6.9 ± 1.4	6.6 ± 1.4†
Family history of diabetes (% of sample)	Yes/no	22.5	24.8	24.7	29.3†
Type 2 diabetes (% of sample)	Yes/no	10.2	18.7*	8.1	21.2†
Fasting blood glucose (mg/dL)	35–628	108 ± 31	117 ± 52*	103 ± 32	120 ± 60†
HDL-C (mg/dL)	9.6–163	43 ± 12	51 ± 17*	57 ± 17	58 ± 18
Blood pressure medications (% of sample)	Yes/no	20.3	34.5*	19.5	44.4†
Ever smoke cigarettes (% of sample)	Yes/no	72.2	71.9	49.5	42.9†
Alcohol intake (g/day)	0–1856	71 ± 121	68 ± 145	24 ± 53	10.6 ± 41.3†
Education level (% of sample)					
<High school	Yes/no	18.0	44.1*	16.3	40.1†
High school or vocational school graduate	Yes/no	39.3	26.3*	50.9	30.0†
≥College graduate	Yes/no	42.7	29.6*	32.7	29.9†
Anthropometric measures					
ABSI ($m/(kg/m^2)^{0.66} \times m^{0.5}$)	0.0404–0.1161	0.0827 ± 0.0032	0.0801 ± 0.0038*	0.0823 ± 0.0058	0.0801 ± 0.0038†
Body adiposity index ($cm/m^{1.5}$–18)	1.1–68.3	26.0 ± 3.5	26.0 ± 4.3	32.6 ± 5.7	35.2 ± 6.5†
BMI (kg/m^2)	14–66	27.5 ± 4.0	27.5 ± 4.2	26.6 ± 5.5	30.8 ± 6.5†
Waist circumference (cm)	20–70	99.7 ± 10.5	97.0 ± 12.8*	93.2 ± 14.9	100.6 ± 16.3†
Waist: height ratio (cm/cm)	0.3–1.1	0.6 ± 0.1	0.6 ± 0.1*	0.6 ± 0.1	0.6 ± 0.1†
Waist: hip ratio (cm/cm)	0.5–1.4	1.0 ± 0.1	0.9 ± 0.1*	0.9 ± 0.1	0.9 ± 0.1†

*$P < 0.0001$ compared with White males; †$P < 0.0001$ compared with White females.

Descriptive statistics evaluated using Pearson Chi-squared tests of independence for categorical variables and *t*-tests for continuous variables. The sample sizes for fasting blood glucose, high-density lipoprotein cholesterol (HDL-C), blood pressure medications, ever smoked cigarettes, alcohol intake, and education level were as follows: White males, n = 5251; Black males, n = 1454; White females, n = 5886; and Black females n = 2333.

[1]Physical activity reflects work + leisure + sport activities calculated from the Baecke questionnaire.[38]

ABSI, A body shape index; BMI, body mass index.

Blood pressure medications were used by more Blacks than Whites. More White and Black males had ever-smoked cigarettes than White and Black females. White and Black males had higher daily alcohol intake than White and Black females. More Whites were college educated than Blacks.

Univariate and bivariate associations between anthropometric measures and T2DM

Table 2 lists the odds ratios (ORs) for each anthropometric measure from univariate and bivariate analyses for all race–gender groups. In bivariate models, we singly adjusted for each covariate to observe the risk effect on the associations between the various anthropometric measures and T2DM. The highest ORs were observed for WHR in every race and gender group in the univariate and bivariate analyses. The ABSI had the lowest ORs among White and Black males and White females, whereas BAI had the lowest ORs among Black females.

Multivariate associations of anthropometric measures and T2DM

Table 3 lists the ORs from multivariate analyses for each race–gender group. In general, the largest ORs for T2DM across race and gender groups were for anthropometric measures that included WC alone or relative to height or hip circumference (i.e. WC, WHtR, and WHR). The WHR had the highest adjusted ORs for White and Black males and females, whereas ABSI was the poorest anthropometric discriminator of T2DM, as observed by its highest AIC and lowest ROC C-statistic for all race–gender groups. In addition, ABSI had the lowest ORs for all race–gender groups except for Black females. The WHtR consistently displayed best fit indices for T2DM, as indicated by the lowest AIC and highest ROC C-statistic values among White males, whereas WHR had the best fit for Black males, White females, and Black females. However, as indicated in Table 3, BMI, WC, WHtR, and WHR did not differ significantly in their ability to discriminate T2DM among White males ($P = 0.2422$) and Black males ($P = 0.5146$). Furthermore, although WHR had the best fit AIC and ROC indices for T2DM among White and Black females, WC and WHtR had comparable discriminatory ability as WHR among White females ($P = 0.9495$). The WHR was the best anthropometric discriminator among Black females ($P < 0.0001$). Generally, these discriminators were stronger than ABSI and BAI in predicting T2DM ($P < 0.0001$). Among White males, covariate-adjusted ABSI did not perform better than covariates alone in discriminating between T2DM cases from non-cases ($P = 0.3731$). These ROC curves are shown in Fig. 1.

We further investigated case identifier values associated with T2DM for each anthropometric measure within race–gender groups, as indicated in Table 3. In general, Black males and Black females had lower case identifier values than their White counterparts. For example, the case identifier values for WHR were 0.97 for White males, 0.93 for Black males, 0.94 for White females, and 0.92 for Black females. We made no attempt to compare across race or gender groups because the primary interest of the present study was within rather than across groups.

Discussion

We found that anthropometric measures that included WC alone or WC relative to height or hip circumference (i.e. WHtR and WHR) were the strongest discriminators of T2DM across race–gender groups studied. Waist circumference, WHtR, and WHR were the best discriminators of T2DM among White females, whereas WHR was a superior discriminator among Black females. Among White and Black males, BMI, WC, WHtR, and WHR were comparable in their ability to discriminate T2DM. The ABSI was the weakest anthropometric discriminator of T2DM across all race–gender groups, except for Black females. In general, the anthropometric values identifying T2DM cases from non-cases were lower for Blacks than Whites.

Anthropometric measures are useful screening tools for T2DM, obesity, and other cardiometabolic conditions because they are inexpensive and easily accessible. In the present cross-sectional study, several anthropometric measures had comparable ability in discriminating risk for T2DM. These results agree with other studies that reported similar findings among US Whites. Wang et al.[41] found in the Health Professionals Follow-up study, which consisted of predominantly White males, that WC had the highest ROC C-statistic and was similar in discrimination with BMI, but better than WHR in predicting risk for T2DM. Mbanya et al.[42] reported that WC and, to a lesser extent, WHtR were stronger than BMI and WHR in their ability to discriminate T2DM in a Cameroonian population. Xiao et al.[43] found that WHtR was the best discriminator of T2DM and had the highest correlation with blood glucose measures among Chinese males and females compared with BMI, WC, WHR, and the poorest discriminator BAI.

In meta-analyses, WHtR was found to be a better discriminator of T2DM and other cardiovascular risk factors than WC and BMI in men and women in the

Table 2 Univariate and bivariate analyses for anthropometric discriminators, adjusted for each covariate, on type 2 diabetes status for all American participants by gender and race

Model	ABSI	Body adiposity index	BMI	Waist circumference	WHtR	WHR
White males						
Univariate analysis	1.37 (1.19–1.57)	2.08 (1.81–2.40)	1.96 (1.76–2.18)	2.03 (1.82–2.27)	2.28 (2.03–2.57)	2.52 (2.19–2.90)
Bivariate analysis						
Age adjusted (5-year increments)	1.26 (1.09–1.45)	2.08 (1.80–2.40)	2.05 (1.84–2.28)	2.09 (1.87–2.33)	2.29 (2.03–2.58)	2.44 (2.12–2.81)
Physical activity adjusted	1.26 (1.10–1.46)	2.00 (1.73–2.30)	1.91 (1.72–2.12)	1.96 (1.75–2.19)	2.20 (1.95–2.48)	2.41 (2.09–2.77)
Family history of diabetes adjusted	1.37 (1.19–1.57)	2.06 (1.78–2.37)	1.94 (1.74–2.16)	2.02 (1.80–2.25)	2.25 (1.99–2.54)	2.44 (2.12–2.82)
Black males						
Univariate analysis	1.51 (1.27–1.78)	1.76 (1.47–2.11)	1.73 (1.51–1.99)	1.83 (1.59–2.11)	1.98 (1.70–2.32)	2.61 (2.15–3.18)
Bivariate analysis						
Age adjusted (5-year increments)	1.42 (1.20–1.69)	1.77 (1.48–2.13)	1.77 (1.54–2.03)	1.82 (1.58–2.10)	1.96 (1.68–2.29)	2.53 (2.08–3.09)
Physical activity adjusted	1.43 (1.21–1.69)	1.79 (1.49–2.14)	1.76 (1.53–2.03)	1.83 (1.59–2.11)	1.97 (1.69–2.30)	2.53 (2.08–3.08)
Family history of diabetes adjusted	1.50 (1.26–1.77)	1.72 (1.43–2.07)	1.71 (1.48–1.96)	1.80 (1.56–2.08)	1.96 (1.67–2.29)	2.64 (2.17–3.22)
White females						
Univariate analysis	1.62 (1.49–1.77)	1.87 (1.71–2.04)	2.05 (1.89–2.22)	2.28 (2.09–2.47)	2.22 (2.05–2.40)	2.92 (2.61–3.27)
Bivariate analysis						
Age adjusted (5-year increments)	1.54 (1.41–1.69)	1.86 (1.70–2.03)	2.08 (1.92–2.25)	2.25 (2.07–2.45)	2.18 (2.01–2.37)	2.85 (2.55–3.20)
Physical activity adjusted	1.55 (1.42–1.70)	1.79 (1.64–1.96)	1.99 (1.84–2.16)	2.21 (2.03–2.40)	2.15 (1.99–2.34)	2.82 (2.52–3.16)
Family history of diabetes adjusted	1.60 (1.47–1.74)	1.83 (1.67–2.00)	2.02 (1.86–2.19)	2.23 (2.05–2.43)	2.18 (2.01–2.36)	2.83 (2.53–3.17)
Black females						
Univariate analysis	1.56 (1.43–1.71)	1.32 (1.21–1.45)	1.42 (1.31–1.53)	1.68 (1.54–1.83)	1.64 (1.51–1.79)	2.20 (1.97–2.46)
Bivariate analysis						
Age adjusted (5-year increments)	1.46 (1.33–1.60)	1.32 (1.21–1.45)	1.45 (1.34–1.57)	1.66 (1.52–1.81)	1.62 (1.49–1.76)	2.09 (1.87–2.34)
Physical activity adjusted	1.52 (1.39–1.67)	1.30 (1.19–1.43)	1.40 (1.29–1.51)	1.65 (1.51–1.79)	1.61 (1.48–1.75)	2.15 (1.92–2.40)
Family history of diabetes adjusted	1.59 (1.45–1.74)	1.30 (1.19–1.42)	1.39 (1.28–1.50)	1.66 (1.52–1.81)	1.62 (1.49–1.77)	2.19 (1.96–2.46)

Data show odds ratios with 95 % confidence intervals in parentheses.

Models were constructed using logistic regression, with type 2 diabetes mellitus (T2DM) as a response to each anthropometric measure as the exposure variable (i.e. A body shape index [ABSI], body adiposity index, body mass index [BMI], waist circumference, waist: hip ratio [WHR], or waist: height ratio [WHtR]) adjusted for age (5-year increments) or physical activity (Baecke units) or a family history of diabetes (yes/no).

Table 3 Multivariate analysis for anthropometric discriminators, adjusted for covariates, on type 2 diabetes status for all American participants by gender and race

Models	ABSI	Body adiposity index	BMI	Waist circumference	WHtR	WHR
White males						
Anthropometric measure	1.18 (1.02–1.37)	1.99 (1.72–2.30)	1.98 (1.77–2.21)	2.02 (1.80–2.27)	2.19 (1.94–2.48)	2.29 (1.98–2.65)
Age (5-year increments)	1.30 (1.19–1.41)	1.32 (1.21–1.43)	1.39 (1.27–1.51)	1.37 (1.26–1.49)	1.33 (1.22–1.45)	1.29 (1.18–1.40)
Physical activity	0.86 (0.81–0.93)	0.88 (0.82–0.94)	0.89 (0.83–0.95)	0.91 (0.85–0.97)	0.91 (0.85–0.98)	0.91 (0.85–0.97)
Family history of diabetes	2.49 (2.07–3.01)	2.43 (2.01–2.94)	2.40 (1.98–2.91)	2.43 (2.01–2.95)	2.37 (1.96–2.88)	2.34 (1.93–2.83)
Case identifier	0.0817	28.34	27	99.5	0.58	0.97
Model AIC	3351.68	3276.63	3210.77	3214.42	3201.14[1]	3223.67
ROC C-statistic	0.658 (0.634–0.683)	0.696 (0.673–0.719)	0.724 (0.702–0.746)	0.720 (0.698–0.742)	0.726 (0.703–0.748)[2]	0.719 (0.697–0.741)
Black males						
Anthropometric measure	1.34 (1.13–1.60)	1.75 (1.46–2.11)	1.77 (1.53–2.04)	1.78 (1.55–2.06)	1.92 (1.65–2.25)	2.47 (2.02–3.02)
Age (5-year increments)	1.17 (1.04–1.31)	1.23 (1.09–1.38)	1.26 (1.12–1.41)	1.21 (1.08–1.36)	1.20 (1.06–1.35)	1.12 (0.99–1.26)
Physical activity	0.87 (0.79–0.96)	0.84 (0.76–0.92)	0.83 (0.75–0.92)	0.84 (0.76–0.93)	0.85 (0.77–0.93)	0.88 (0.79–0.97)
Family history of diabetes	2.31 (1.74–3.06)	2.28 (1.71–3.03)	2.28 (1.71–3.04)	2.22 (1.66–2.97)	2.24 (1.68–2.99)	2.31 (1.73–3.09)
Case identifier	0.0800	28.14	26	99.5	0.56	0.93
Model AIC	1409.37	1383.09	1355.80	1353.44	1347.32	1334.29[1]
ROC C-statistic	0.653 (0.618–0.688)	0.684 (0.650–0.719)	0.709 (0.675–0.743)	0.714 (0.680–0.747)	0.711 (0.678–0.744)[2]	0.715 (0.681–0.748)
White females						
Anthropometric measure	1.47 (1.34–1.61)	1.76 (1.60–1.92)	2.00 (1.84–2.17)	2.16 (1.98–2.35)	2.09 (1.92–2.27)	2.68 (2.39–3.01)
Age (5-year increments)	1.17 (1.07–1.28)	1.29 (1.18–1.40)	1.34 (1.23–1.47)	1.25 (1.14–1.37)	1.21 (1.11–1.33)	1.09 (0.99–1.19)
Physical activity	0.82 (0.77–0.89)	0.84 (0.78–0.90)	0.86 (0.79–0.92)	0.87 (0.81–0.94)	0.88 (0.82–0.94)	0.86 (0.80–0.93)
Family history of diabetes	2.60 (2.14–3.16)	2.54 (2.08–3.09)	2.50 (2.04–3.05)	2.42 (1.97–2.96)	2.38 (1.94–2.92)	2.34 (1.91–2.86)
Case identifier	0.0818	32.93	28	100.5	0.64	0.94
Model AIC	3077.61	3011.06	2878.11	2827.74	2834.21	2818.96[1]
ROC C-statistic	0.707 (0.682–0.732)	0.733 (0.709–0.756)	0.776 (0.754–0.798)	0.788 (0.766–0.809)	0.788 (0.766–0.809)	0.790 (0.768–0.811)[2]
Black females						
Anthropometric measure	1.44 (1.31–1.58)	1.28 (1.17–1.41)	1.40 (1.29–1.52)	1.61 (1.47–1.76)	1.57 (1.44–1.71)	2.04 (1.82–2.29)
Age (5-year increments)	1.36 (1.23–1.49)	1.47 (1.35–1.61)	1.51 (1.37–1.65)	1.45 (1.32–1.60)	1.44 (1.31–1.58)	1.35 (1.23–1.49)
Physical activity	0.86 (0.80–0.93)	0.85 (0.79–0.91)	0.86 (0.80–0.92)	0.87 (0.81–0.93)	0.87 (0.81–0.93)	0.87 (0.81–0.94)
Family history of diabetes	2.65 (2.14–3.27)	2.55 (2.07–3.15)	2.48 (2.01–3.07)	2.47 (2.00–3.07)	2.48 (2.00–3.07)	2.52 (2.02–3.13)
Case identifier	0.0815	34.31	31	97.5	0.60	0.92
Model AIC	2308.68	2342.95	2302.17	2254.39	2260.45	2200.41[1]
ROC C-statistic	0.715 (0.690–0.739)	0.701 (0.677–0.726)	0.723 (0.700–0.746)	0.744 (0.722–0.767)	0.744 (0.721–0.766)	0.757 (0.734–0.779)[2]

Data show odds ratios with 95 % confidence intervals in parentheses.

Models were constructed using logistic regression, with type 2 diabetes mellitus (T2DM) as a response to each anthropometric measure (i.e. A body shape index [ABSI], body adiposity index, body mass index [BMI], waist circumference, waist: hip ratio [WHR], or waist: height ratio [WHtR]) adjusted for age (5-year increments), physical activity (Baecke units), and family history of diabetes (yes/no). The case identifier was used to identify the value for each anthropometric measure that distinguished participants with T2DM from those without T2DM.

[1]Best-fit Akaike information criterion (AIC) model (lowest AIC value).

[2]Best-fit receiver operating characteristic (ROC) concordance statistic (C-statistic) model (highest ROC C-statistic value).

Bolded values indicate anthropometric measures that were comparable with each other.

For White and Black males, the ROC C-statistics for BMI, waist circumference, WHtR, and WHR were not significantly different.

For White females, the ROC C-statistics for waist circumference, WHtR, and WHR were not significantly different.

For Black females, the ROC C-statistics did not differ between ABSI and BMI or between waist circumference and WHtR.

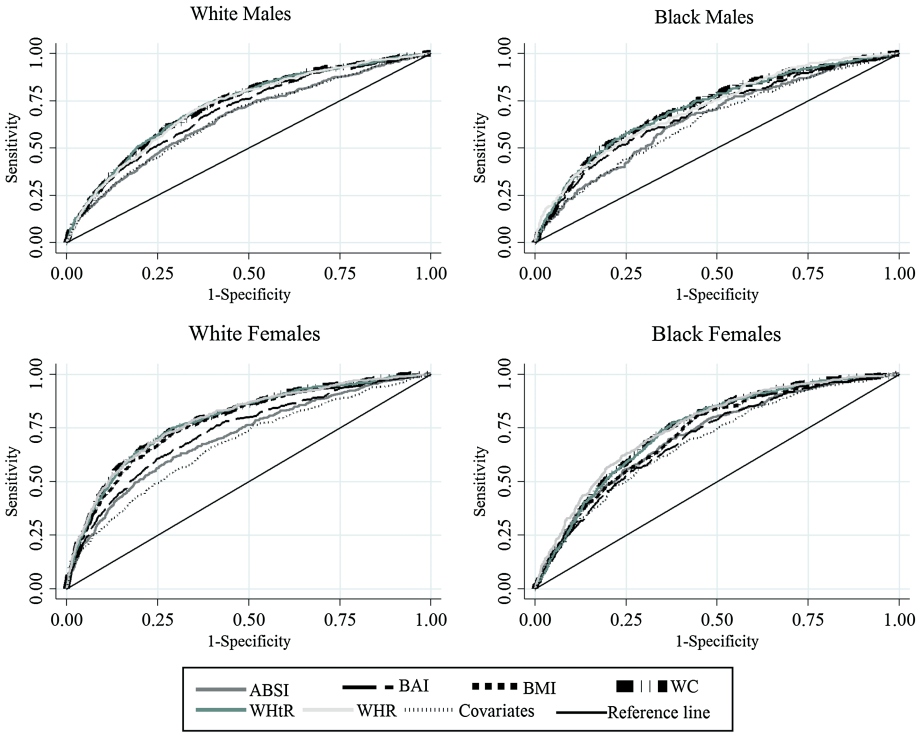

Figure 1 Receiver operating characteristic (ROC) curves in (a) White males, (b) Black males, (c) White females, and (d) Black females. The ROC curves were constructed for type 2 diabetes mellitus as a response to each anthropometric measure (A body shape index [ABSI], body adiposity index [BAI], body mass index BMI], waist circumference [WC], waist: height ratio [WHtR], and waist: hip ratio [WHR]) adjusting for covariates (age, physical activity, and family history of diabetes) for White and Black American males and females.

Caribbean, Asia, Europe, Australia, North America, South America, and the Middle East.[17,22,44] However, in another meta-analysis, WC or WHR were better discriminators of T2DM cases in cross-sectional studies, whereas longitudinal studies favored BMI, WC, WHtR, or WHR.[12] Other studies showed that WHtR and WHR were better discriminators of dyslipidemia, metabolic syndrome, and coronary heart disease than BMI.[17,23,45]

Although higher values of all anthropometric measures were associated with increased risk of T2DM in our sample, ABSI, the newest anthropometric measure, was the worst discriminator of T2DM across race–gender groups, except among Black females. Fujita et al.[32] found ABSI to be weaker than WC and BMI for predicting T2DM, high blood pressure, and dyslipidemia among Japanese adults. He et al.[11] investigated ABSI in a Chinese population and reported that ABSI was associated with risk for T2DM, but that WC had better discriminatory power than BMI or ABSI. Similarly, Song et al.[30] found that BMI and ABSI were weaker discriminators than other anthropometric measures for predicting cardiovascular disease mortality among Europeans. Cheung[31] reported that, in an Indonesian sample, ABSI was less strongly associated with incident high blood pressure than BMI and WC and was the poorest discriminator compared with BMI, WC, WHtR, WHR, and hip circumference. Abete et al.[33] found that WC, WHR, and ABSI were associated with stroke in Spanish European men, whereas BMI showed no association.

The case identifier values in the present study were used to distinguish T2DM cases from non-cases. These values are not meant to reflect cut-off points that define T2DM disease risk. The World Health Organization (WHO) cut-off points[25] were developed to reflect the risk of developing T2DM, metabolic syndrome, high blood pressure, and cardiovascular disease. Cut-off points recommended by the WHO are based on relationships between adiposity and disease risk while allowing for global use and region-specific differences.[25] For example, Asians have lower BMI cut-off points that are associated with the risk of developing T2DM[46] and lower WHR values associated with metabolic risk compared with Whites.[25] The WHO recommends gender-specific cut-off points for WC and WHR to identify risk for metabolic diseases.[25]

A limited number of studies have investigated race-specific anthropometric cut-off points for Blacks. A study of Caribbean Blacks in the UK suggested cut-off points lower than for Whites, in agreement with the present

study, but did not provide enough evidence to set specific cut-off points by race within gender groups.[47] In contrast, other studies report higher cut-off points for Blacks than Whites. Katzmarzyk et al.[48] reported BMI and WC risk identification thresholds that were approximately 3 kg/m^2 and 5 cm, respectively, higher in Black American women than in White American women in a cross-sectional study of cardiometabolic risk factors. Lutsey et al.[49] found that at the 95th percentile for WC, Black Americans had a higher WC than White Americans, Chinese Americans, or Hispanic Americans (125 vs 121, 104, and 121 cm, respectively. Frank et al.[50] showed that WHR was the best anthropometric discriminator of T2DM for Ghanaian men and women, with optimal cut-off points of ≥0.90 for men and ≥0.88 for women. Blacks from different parts of the world have varying genetic admixture, which may influence body shape, body composition, and anthropometric measures.[51] Therefore, optimal anthropometric cut-off points for Blacks may vary across different regions in the world.

The disagreement between studies regarding optimal WC cut-off points is ongoing, and further longitudinal data relating WC to T2DM risk are needed. Currently, the International Diabetes Federation (IDF) and the American Heart Association recommend the use of population and region-specific WC guidelines.[52] The IDF Task Force on Epidemiology and Prevention, the National Heart, Lung, and Blood Institute, the American Heart Association, the World Heart Federation, the International Atherosclerosis Society, and the International Association for the Study of Obesity issued a Joint Scientific Statement on guidelines for metabolic syndrome that recognize that WC cut-off points of 80 cm for women and 94 cm for men are associated with higher risk of developing T2DM and cardiovascular disease.[53] Case identifier values in the present ARIC sample were higher than the WHO cut-off points, likely because our cases already had T2DM and were at risk long before its development. These values are not meant to identify the earliest onset of T2DM, but to distinguish between individuals with and without T2DM in our sample. Because the anthropometric case identifier values in the present study were lower for Black Americans than White Americans, further research is needed to identify race- and gender-specific cut-off points for each anthropometric measure.

In the present study, and in general, Black Americans had a higher proportion of diagnosed T2DM and were heavier than White Americans. Type 2 diabetes mellitus is a metabolic condition that develops over time and is associated with higher anthropometric values. Most of the anthropometric case identifier values associated with T2DM risk in the present study were lower for Blacks than Whites, except for BMI in Black females. The risk of T2DM and other cardiometabolic risks have been reported to develop at a BMI lower than 25 kg/m^2, which is the BMI cut-off points for defining overweight.[54,55] This phenomenon has been observed in other studies,[56,57] which reinforces the findings of the present study.

The present study has limitations and advantages. A potential limitation is the cross-sectional rather than longitudinal design, so issues in temporality may surface. Another potential limitation was the measurement of WC at the umbilicus in the ARIC protocol,[37] which differs from the sites commonly use in the other epidemiologic studies (e.g. superior border of the iliac crest).[58,59] Because approximately one-third of the US population with T2DM is undiagnosed, there may be some misclassification of individuals with T2DM in the ARIC cohort that may have biased our effect estimates towards the null. In addition, we did not take into consideration whether individuals in our sample had prediabetes, (i.e. blood glucose values between normal and the cut-off point for diabetes). Another limitation is that individuals in our sample who were categorized as having T2DM, but whose blood glucose levels were well controlled, may have had anthropometric measures that are more reflective of individuals without T2DM. For example, they may have been more physically active, consumed a healthier die, or taken medications regularly, and, as such, their metabolic markers may have been similar to those of individuals without T2DM. An advantage of the present study is the large sample size, with representation from four race–gender groups. In addition, the anthropometric measures were obtained at the same anatomical sites for all participants, with high methodological quality control.

In summary, in evaluating the predictive ability of several anthropometric discriminators, there was not a single measure that was superior to all others among White and Black Americans in the US, except for Black females. In general, however, WC alone or expressed relative to height (WHtR) or hip (WHR) circumference performed the best in discriminating T2DM among White and Black males and females. Body mass index was a comparable discriminator among American males but not American females. Importantly, the risk of T2DM increased with higher values for all anthropometric measures among all race–gender groups. Because there is no consensus agreement to identity optimal anthropometric cut-off points for Black Americans, further longitudinal research is needed to identify the optimal anthropometric measures and their corresponding cut-off points to discriminate T2DM risk for each race–gender.

Disclosure

None of the authors has any conflicts of interest.

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