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ORIGINAL RESEARCH

Trends in Prevalence, Treatment, and Relationship of Metabolic Syndrome and Individual Components by Race/Ethnicity, 1999-2018

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ABSTRACT

BACKGROUND Nationally representative data on recent trends in racial/ethnic differences in metabolic syndrome (MetS) prevalence and treatment are sparse.

OBJECTIVES The purpose of this study was to examine 20-year trends in the prevalence, treatment, and interrelationships of MetS and its individual components among U.S. adults, overall and by race/ethnicity.

METHODS We evaluated trends from 1999 to 2018 in 20,397 adults using data from the National Health and Nutrition Examination Survey. Age-standardized prevalence estimates were calculated for MetS, its components, and related prescription drug use. Trends were assessed using weighted linear regression, and racial/ethnic disparities were examined using *t*-tests.

RESULTS The mean age was 47.5 (47.4-47.6) years; 51.3% were female; 77.9%, 12.8%, and 9.4% were White, Black, and Hispanic, respectively. MetS prevalence increased significantly from 1999 to 2018 across all groups ($P < 0.001$). Among MetS components, waist circumference and fasting glucose increased across all groups, while triglycerides increased only among Black individuals. Lipid-lowering medication use increased ($P < 0.001$), but racial/ethnic disparities persisted. Compared to White individuals, Hispanic individuals had lower antihypertensive and lipid-lowering medication use ($P < 0.01$). Despite increased prescriptions, <65% of eligible individuals received lipid-lowering therapy, and <35% received antihyperglycemic therapy, highlighting substantial treatment gaps. Racial/ethnic differences in MetS component relationships were observed: blood pressure played a larger role in Black individuals, while fasting glucose was more prominent in Hispanic individuals.

CONCLUSIONS MetS prevalence has increased over 2 decades. Persistent racial/ethnic disparities exist in antihypertensive, antihyperglycemic, and lipid-lowering medication use. Across all racial/ethnic subgroups, large opportunities remain for improving treatment strategies among individuals with medication indications. (JACC Adv. 2025;4:101785)

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ABBREVIATIONS AND ACRONYMS

ASCVD = atherosclerotic cardiovascular disease

HDL-C = high-density lipoprotein cholesterol

MetS = metabolic syndrome

NHANES = National Health and Nutrition Examination Survey

Metabolic syndrome (MetS), defined as the presence of at least 3 out of 5 metabolic abnormalities (abdominal obesity, dyslipidemia [low high-density lipoprotein (HDL) or hypertriglyceridemia], elevated blood pressure, and hyperglycemia), is associated with increased risk of cardiovascular disease and all-cause mortality.[1] Over the past few decades, the prevalence of individual MetS components has changed substantially with persistent racial/ethnic disparities. Prevalence of obesity has tripled since the 1960s and over two-thirds of U.S. adults were either overweight or obese in 2018, with highest rates among Black and Hispanic populations.[2,3] Elevated blood pressure and diabetes have also increased in the last decade among all racial/ethnic groups,[4,5] resulting in a larger proportion of adults with MetS and thus at high risk for adverse outcomes. Given the positive association between obesity and elevated blood pressure and hyperglycemia,[6] hypertension and diabetes may become more dominant health challenges as prevalence of obesity continues to increase. To mitigate the adverse effect of MetS and to identify intervention targets requires a greater understanding of the dynamic patterns of MetS components, their treatment, and relationships over time and by population subgroups.

Previous studies have assessed the trends in prevalence of MetS and its components in the U.S. population.[7-12] However, most reports used older or shorter study periods and did not assess trends in treatment of individual MetS components or treatment heterogeneity by population subgroups. As such, we lack a recent comprehensive view of how MetS components and their treatment have changed during a 20-year period overall and by race/ethnicity. Additionally, previous studies did not quantify the relationships between individual MetS components and how these relationships change over time. In particular, it is important to investigate any heterogeneity in the relationships across racial/ethnic subgroups because racial and ethnic minorities are more likely to have metabolic abnormalities and experience related complications.[13,14]

Accordingly, we leveraged data from the National Health and Nutrition Examination Survey (NHANES) to evaluate the secular trends in prevalence, treatment, and relationship of MetS and individual components, overall and by race/ethnicity from 1999 to 2018. Such knowledge could inform ways to target interventions for MetS, provide insight into mechanisms, and project future health care needs.

METHODS

STUDY DESIGN AND POPULATION. We included data from 55,081 adults, aged ≥20 years, enrolled in the NHANES for the years 1999-2018. The NHANES is a series of cross-sectional, weighted, multistage sampled surveys that provide nationally representative estimates on the noninstitutionalized U.S. population.[15] Since 1999, NHANES has been conducted in 2-year cycles. All survey participants received in-home interviews; among these individuals, a random subsample also received standardized physical examinations conducted in mobile examination centers and laboratory tests using blood and urine specimens provided by participants during the physical examination. For the current analysis, we used data from 10 cycles conducted from 1999 through 2018 to assess 20-year trends.[16]

We categorized individuals into 3 mutually exclusive subgroups based on their self-reported race/ethnicity information: non-Hispanic Black, Hispanic, and non-Hispanic White subgroups. For simplicity, we hereafter refer to the study groups as Black, Hispanic, and White individuals. We excluded individuals who identified as Asian, Alaskan Native or American Indian, or "other" race (n = 4,741) due to small numbers. We also excluded women who were pregnant at the time of interview (n = 1,374). In addition, we excluded individuals who were not selected for the fasting sample or did not fast at least 8.5 hours (n = 28,569).

DEFINITIONS OF MetS AND ITS COMPONENTS. We defined MetS using the criteria and definition published in the joint scientific statement on MetS.[17] These criteria defined MetS when 3 out of the 5 components were present: 1) elevated waist circumference (≥88 cm for women and ≥102 cm for men); 2) elevated triglycerides (≥150 mg/dL) or drug treatment for elevated triglycerides; 3) reduced HDL cholesterol (HDL-C) (<40 mg/dL for men and <50 mg/dL for women) or drug treatment for reduced HDL-C; 4) elevated blood pressure (systolic ≥130 mm Hg, or diastolic ≥85 mm Hg, or both) or antihypertensive drug treatment for a history of hypertension; and 5) elevated fasting glucose (≥100 mg/dL) or drug treatment for elevated glucose. In this analysis, we calculated the estimated proportion of adults who met each component criterion and who met the

formal definition of MetS across the study periods (individuals with missing or unknown data were included in a separate response category).

MEASUREMENTS OF MetS COMPONENTS. Waist circumference was measured at the high point of the iliac crest at minimal respiration to the nearest 0.1 cm. Blood pressure was measured by trained staff using a mercury sphygmomanometer after the participant rested quietly in a seated position for at least 5 minutes. Up to 4 attempts were made to collect 3 blood pressure readings in the mobile examination center; the average of all available measures was used. Concentrations of serum triglyceride, HDL-C, and plasma glucose were measured from the blood samples using standardized protocols. HDL-C was measured after the precipitation of other lipoproteins with a heparin-manganese chloride mixture. Both triglyceride and HDL-C analyses were performed on a Hitachi 704 Analyzer. Plasma glucose concentrations were determined using a hexokinase-mediated reaction Roche/Hitachi Cobas C 501 Chemistry Analyzer.[18]

TREATMENT OF MetS COMPONENTS. Antihypertensive medication use was defined as an affirmative response to "are you now taking prescribed medicine to lower your blood pressure?" Antihyperglycemic medication use was defined as an affirmative response to the questions, "Are you now taking prescribed medicine to lower your blood sugar?" or "Are you now taking insulin?" or evidence of the use of insulin sensitizers (eg, metformin, thiazolidinediones) or antidiabetic drugs (eg, liraglutide, canagliflozin, empagliflozin, dapagliflozin) within the 30-day period prior to the survey date. Lipid-lowering medication use was defined as an affirmative response to "Are you now taking prescribed medicine to lower your blood cholesterol?" The proportion of antihypertensive medication use was defined as antihypertensive medication use among individuals with elevated blood pressure or treated for hypertension. The proportion of antihyperglycemic medication use was defined as antihyperglycemic medication use among individuals with elevated fasting glucose or with glycohemoglobin A1C ≥6.5% or treated for elevated fasting glucose. The proportion of lipid-lowering medication use was defined as lipid-lowering medication use among individuals having a history of coronary artery disease or stroke or having a 10-year atherosclerotic cardiovascular disease (ASCVD) risk ≥7.5% or treated for high serum cholesterol. The 10-year ASCVD risk was estimated using the 2013 American College of Cardiology/American Heart Association ASCVD risk calculator.[19]

OTHER SOCIODEMOGRAPHIC, BEHAVIORAL, AND CLINICAL VARIABLES. We included other variables in the analysis, including age (in years), sex (male, female), education level (less than high school, high school diploma, some college, bachelor's degree or higher), family income (based on the percent of family income relative to the federal poverty limit from the Census Bureau: high/middle income [≥200%] and low-income [<200%]), insurance status (insured, uninsured), marital status (married, unmarried), employment status (working, not in the labor force, unemployed), smoking status (current, former, never smoker), alcohol intake (never, former, current drinker), and body mass index. Detailed definitions of the covariates are reported in Supplemental Table 1. Information on all sociodemographic variables was available for all years and responses coded as "unknown" or "not ascertained" were analyzed under a separate category of "unknown."

STATISTICAL ANALYSIS. All analyses used methods appropriate for structured survey data, incorporating strata and weights to produce nationally representative estimates. Following the NHANES guidance, fasting sample weights were pooled and divided by the number of years studied.[15] The survey design was age-standardized using proportions for 20-year age groups based on the 2010 U.S. census standard population. We combined every 2 NHANES cycles to produce sufficient sample size in each racial/ethnic subgroup. We assessed missingness for all MetS components and found that missing rates were consistently below 6%. Consistent with prior studies,[8,10] participants with missing data on any MetS component were excluded from the analysis to ensure completeness of the reported prevalence estimates and trends.

We first described the sociodemographic and clinical characteristics of study participants by race/ethnicity. Continuous variables (eg, age) were presented as mean ± SE. Categorical variables (eg, sex, education, income) were represented as age-standardized proportions with 95% CIs to account for the NHANES survey design and ensure comparability across demographic groups. For each 2-year cycle, we calculated the age-standardized prevalence of MetS and its 5 components, overall and stratified by race/ethnicity and sex. Additionally, we assessed the age-standardized prevalence of prescription drug use related to MetS components. We

TABLE 1 Sociodemographic and Clinical Characteristics of U.S. Adults With Metabolic Syndrome by Race/Ethnicity, 1999-2018

	Total	Black	Hispanic	White
Total	20,397	5,224 (12.8% [11.4-14.1])	4,282 (9.4% [8.2-10.6])	10,891 (77.9% [76.0-79.7])
Age (y)				
20-39	6,372 (36.7% [36.7-36.7])	1,739 (43.2% [41.4-44.9])	1,575 (55.5% [52.9-58.2])	3,058 (33.4% [32.9-33.9])
40-59	6,511 (37.9% [37.9-37.9])	1,762 (38.0% [36.3-39.7])	1,387 (32.8% [31.0-34.6])	3,362 (38.5% [38.2-38.9])
60-79	5,853 (21.1% [20.7-21.4])	1,525 (16.8% [15.7-17.8])	1,191 (10.5% [9.1-11.8])	3,137 (23.1% [22.5-23.6])
80+	1,661 (4.2% [3.9-4.6])	198 (2.1% [1.6-2.5])	129 (1.2% [0.9-1.5])	1,334 (5.0% [4.6-5.4])
Sex				
Women	10,296 (51.3% [50.6-52.0])	2,716 (55.2% [53.7-56.7])	2,161 (46.8% [45.4-48.2])	5,419 (51.2% [50.4-52.1])
Men	10,101 (48.7% [48.0-49.4])	2,508 (44.8% [43.3-46.3])	2,121 (53.2% [51.8-54.6])	5,472 (48.8% [47.9-49.6])
Education level				
More than high school	9,768 (58.6% [56.8-60.3])	2,486 (51.2% [49.2-53.3])	1,067 (29.8% [27.4-32.2])	6,215 (63.2% [61.0-65.4])
High school	4,949 (24.9% [23.8-26.1])	1,343 (26.2% [24.8-27.6])	751 (22.4% [20.2-24.7])	2,855 (25.0% [23.6-26.4])
Less than high school	5,650 (16.5% [15.5-17.6])	1,380 (22.6% [20.7-24.4])	2,456 (47.8% [45.5-50.0])	1814 (11.8% [10.6-13.0])
Family income				
High/middle income	9,811 (66.5% [64.8-68.2])	2,232 (48.2% [45.6-50.8])	1,321 (36.2% [33.2-39.2])	6,258 (72.8% [70.8-74.9])
Low income	8,855 (33.5% [31.8-35.2])	2,436 (51.8% [49.2-54.4])	2,473 (63.8% [60.8-66.8])	3,946 (27.2% [25.1-29.2])
Insurance status				
Uninsured	4,214 (17.1% [16.1-18.0])	1,058 (24.0% [22.0-26.1])	1,700 (48.5% [46.0-51.1])	1,456 (12.7% [11.5-13.8])
Insured	16,089 (82.9% [82.0-83.9])	4,133 (76.0% [73.9-78.0])	2,555 (51.5% [48.9-54.0])	9,401 (87.3% [86.2-88.5])
Marital status				
Married/living with partner	11,772 (65.5% [64.3-66.7])	2,225 (44.7% [42.6-46.7])	2,746 (68.6% [66.5-70.8])	6,801 (68.4% [67.1-69.7])
Unmarried	7,801 (34.5% [33.3-35.7])	2,671 (55.3% [53.3-57.4])	1,338 (31.4% [29.2-33.5])	3,792 (31.6% [30.3-32.9])
Employment status				
Not in labor force	8,114 (30.4% [29.5-31.4])	1899 (28.5% [27.1-30.0])	1,478 (23.9% [21.9-26.0])	4,737 (31.5% [30.4-32.7])
Unemployed	748 (3.4% [3.1-3.8])	278 (6.9% [5.8-8.0])	144 (4.2% [3.3-5.0])	326 (2.8% [2.4-3.2])
With a job/working	11,018 (66.1% [65.1-67.1])	2,874 (64.5% [62.7-66.4])	2,514 (71.9% [69.9-74.0])	5,630 (65.7% [64.5-66.9])
Smoking status				
Current smoker	4,350 (20.8% [19.6-21.9])	1,285 (24.4% [22.7-26.0])	687 (16.6% [14.9-18.3])	2,378 (20.7% [19.3-22.1])
Former smoker	5,148 (25.3% [24.3-26.3])	920 (14.2% [13.2-15.3])	931 (18.9% [17.5-20.3])	3,297 (27.9% [26.6-29.1])
Never smoker	10,517 (52.2% [50.9-53.5%])	2,932 (59.8% [57.9-61.8])	2,585 (63.0% [60.9-65.1])	5,000 (49.7% [48.1-51.3])
Alcohol intake				
Current	13,157 (77.1% [75.8-78.5])	2,992 (67.1% [65.1-69.2])	2,597 (72.4% [70.5-74.4])	7,568 (79.2% [77.6-80.8])
Former	2,890 (13.1% [12.2-13.9])	883 (17.9% [16.3-19.5])	583 (14.0% [12.5-15.6])	1,424 (12.2% [11.2-13.2])
Never	2,351 (9.8% [8.9-10.7])	684 (14.9% [13.5-16.4])	630 (13.5% [12.0-15.1])	1,037 (8.6% [7.4-9.7])
BMI, kg/m^2				
<25	5,727 (30.8% [29.8-31.8])	1,299 (25.2% [23.7-26.7])	911 (21.0% [19.1-23.1])	3,517 (32.9% [31.7-34.1])
25-<30	6,722 (33.1% [32.2-34.0])	1,506 (28.7% [27.3-30.2])	1,643 (37.8% [35.8-39.7])	3,573 (33.2% [32.2-34.3])
≥30	7,537 (36.1% [35.0-37.2])	2,311 (46.1% [44.4-47.9])	1,650 (41.1% [38.8-43.4])	3,576 (33.9% [32.6-35.2])

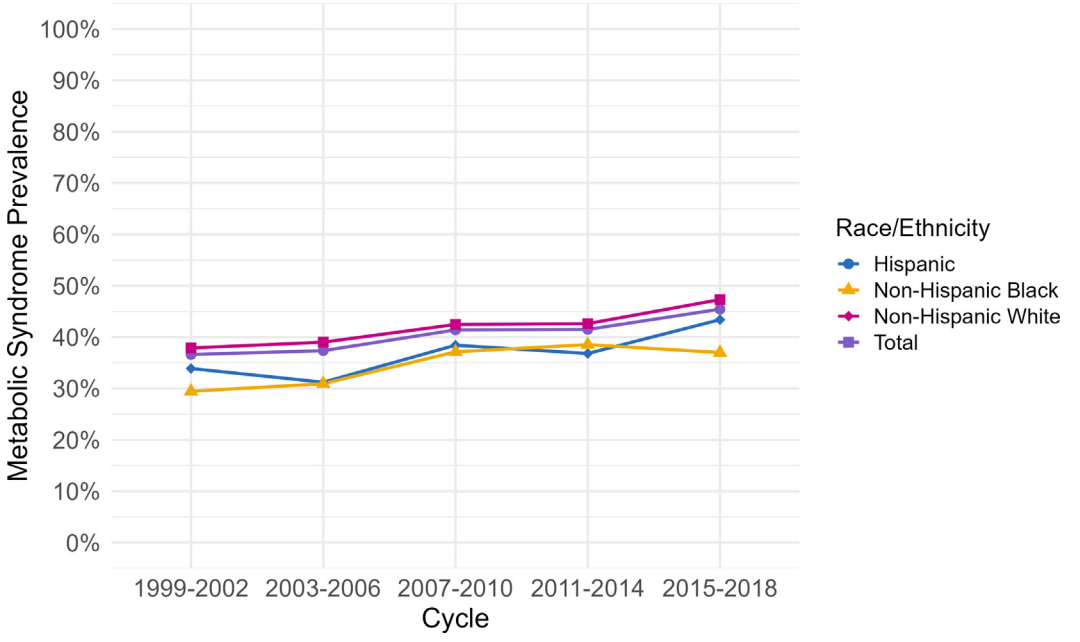
Values are n (% [95% CI]). All percentages were calculated after excluding missing data for each variable. Proportions were age-standardized to the 2010 U.S. census standard population. CIs were included to account for variability introduced by the NHANES survey design.

BMI = body mass index.

then examined trends in the prevalence of MetS, its components, and prescription drug use from 1999 to 2018 using weighted linear regression adjusted for age. We also compared prevalence between 1999-2002 and 2015-2018 to evaluate overall changes and disparities. For each racial/ethnic group (Black, Hispanic, and White), we determined changes in prevalence over time and differences between racial/ethnic groups at each time point. The "Change in difference with Whites" metric reflects how disparities between Black or Hispanic individuals and White individuals evolved between 1999-2002 and 2015-2018. *P* values for all comparisons were computed using *t*-tests.

To identify the primary drivers of MetS within each racial/ethnic subgroup, we used a radar plot to visualize the relative prevalence of MetS components among individuals with and without MetS, both overall and by race/ethnicity, for the period 1999 to 2018. Relative prevalence was calculated as the ratio of the age-standardized prevalence of each MetS component among individuals with MetS to its prevalence among all participants. We then estimated

FIGURE 1 Trends in Metabolic Syndrome Prevalence by Race/Ethnicity



Age-standardized prevalence of metabolic syndrome among U.S. adults, by race and ethnicity.

age-standardized pairwise Pearson correlation coefficients for the 5 MetS components and assessed their significance using *t*-tests. These correlations were presented in heatmaps to illustrate the relationships between MetS components. Finally, we analyzed how these correlations changed over time and varied by race/ethnicity, providing insights into the shifting interconnections among metabolic risk factors.

We considered 2-sided *P* values <0.05 to be statistically significant. All analyses were performed using R 4.0. This study received an exemption for review from the Institutional Review Board at Yale University because the NHANES data are publicly available and deidentified. The study was reported following the Strengthening the Reporting of Observational Studies in Epidemiology reporting guidelines.[20]

RESULTS

POPULATION CHARACTERISTICS. From 55,081 adults aged ≥20 years enrolled from 1999 to 2018, we excluded 1,374 women due to pregnancy. We restricted the study to participants selected for the fasting sample and had laboratory measurements by excluding 28,569 individuals who were not selected for the fasting sample or did not fast at least 8.5 hours. Because of small numbers, we also excluded 4,741 individuals who identified as Asian and Alaskan Native/American Indian and individuals who identified as non-Hispanic and did not select a primary race. Finally, a total of 20,397 nonpregnant adults aged ≥20 years from the NHANES 1999-2018 were included in the analysis (Supplemental Figure 1). Among the study participants, the mean age was 47.5 (47.4-47.6) years, 51.3% (50.6%-52.0%) were women, 12.8% (11.4%-14.1%) were Black, 9.4% (8.2%-10.6%) were Hispanic, and 77.9% (76.0%-79.7%) were White. Compared with White individuals, Black and Hispanic individuals were younger, had lower income and education level, and were less likely to have health insurance (**Table 1**).

TRENDS IN MetS AND INDIVIDUAL COMPONENTS. In 1999 to 2002, the age-standardized prevalence of MetS was 29.4% (26.3%-32.6%) among Black individuals, 33.9% (29.3%-38.5%) among Hispanic individuals, and 37.9% (35.9%-39.8%) among White individuals (**Figure 1**). From 1999 to 2018, the age-standardized prevalence of MetS significantly increased for all racial and ethnic groups ($P < 0.001$ for each; **Table 2**), but the difference between White and other subgroups did not change significantly. In

TABLE 2 Change in Prevalence and Treatment of Metabolic Syndrome and Its Components by Race and Ethnicity, Comparing 1999-2002 vs 2015-2018

	Black Individuals Percentage Points (95% CI)	*P* Value	Hispanic Individuals Percentage Points (95% CI)	*P* Value	White Individuals Percentage Points (95% CI)	*P* Value	Total Percentage Points (95% CI)	*P* Value
Overall prevalence of metabolic syndrome								
Change in prevalence, 1999-2018	+9.53 (5.27-13.79)	<0.001	+10.93 (5.37-16.49)	<0.001	+11.74 (7.90-15.59)	<0.001	+11.07 (8.05-14.09)	<0.001
Difference with White, 1999-2002	−8.44 (−12.07 to −4.81)	<0.001	−4.00 (−9.63 to 1.63)	0.157	-	-	-	-
Difference with White, 2015-2018	−10.32 (−14.86 to −5.79)	<0.001	−3.91 (−8.35 to 0.53)	0.082	-	-	-	-
Change in difference with White, 1999-2018	−2.08 (−7.61 to 3.44)	0.453	−0.86 (−7.81 to 6.09)	0.805	-	-	-	-
Prevalence of elevated blood pressure								
Change in prevalence, 1999-2018	+6.03 (−0.68 to 12.73)	0.077	+6.69 (−0.02 to 13.39)	0.051	−0.32 (−4.23 to 3.60)	0.872	+0.94 (−2.54 to 4.42)	0.592
Difference with White, 1999-2002	+4.54 (0.94-8.15)	0.015	−15.30 (−21.03 to −9.56)	<0.001	-	-	-	-
Difference with White, 2015-2018	+11.63 (6.14-17.12)	<0.001	−7.10 (−12.53 to −1.68)	0.012	-	-	-	-
Change in difference with White, 1999-2018	+6.63 (0.35-12.91)	0.039	+7.09 (−0.66 to 14.85)	0.072	-	-	-	-
Prevalence of elevated fasting glucose								
Change in prevalence, 1999-2018	+20.43 (14.50-26.35)	<0.001	+26.78 (21.19-32.38)	<0.001	+27.44 (23.26-31.61)	<0.001	+26.39 (22.70-30.08)	<0.001
Difference with White, 1999-2002	−7.16 (−12.69 to −1.63)	0.013	+3.96 (−1.12 to 9.05)	0.122	-	-	-	-
Difference with White, 2015-2018	−13.80 (−18.14 to −9.46)	<0.001	+4.26 (−0.05 to 8.56)	0.052	-	-	-	-
Change in difference with White, 1999-2018	−6.97 (−13.74 to −0.19)	0.044	−0.69 (−7.01 to 5.63)	0.828	-	-	-	-
Prevalence of elevated triglyceride								
Change in prevalence, 1999-2018	+5.92 (1.69-10.15)	0.007	−1.06 (−7.17 to 5.04)	0.727	+0.10 (−4.32 to 4.52)	0.963	+0.27 (−3.16 to 3.70)	0.875
Difference with White, 1999-2002	−20.26 (−24.97 to −15.55)	<0.001	−2.73 (−8.73 to 3.26)	0.358	-	-	-	-
Difference with White, 2015-2018	−13.81 (−17.76 to −9.86)	<0.001	−3.06 (−7.34 to 1.22)	0.155	-	-	-	-
Change in difference with White, 1999-2018	+5.84 (−0.21 to 11.88)	0.058	−1.37 (−8.56 to 5.81)	0.703	-	-	-	-
Prevalence of elevated waist circumference								
Change in prevalence, 1999-2018	+9.16 (3.51-14.81)	0.002	+19.22 (13.34-25.11)	<0.001	+15.27 (9.90-20.64)	<0.001	+14.88 (10.58-19.19)	<0.001
Difference with White, 1999-2002	+3.35 (−2.61 to 9.31)	0.259	−2.06 (−7.29 to 3.16)	0.425	-	-	-	-
Difference with White, 2015-2018	−2.32 (−7.72 to 3.08)	0.386	+2.44 (−3.71 to 8.59)	0.423	-	-	-	-
Change in difference with White, 1999-2018	−6.18 (−13.91 to 1.55)	0.115	+3.94 (−4.01 to 11.88)	0.325	-	-	-	-
Prevalence of reduced HDL-C								
Change in prevalence, 1999-2018	+0.84 (−4.72 to 6.40)	0.762	−0.71 (−6.70 to 5.27)	0.811	+1.86 (−2.77 to 6.49)	0.425	+1.34 (−2.25 to 4.93)	0.459
Difference with White, 1999-2002	−6.98 (−12.78 to −1.19)	0.02	+1.19 (−3.90 to 6.29)	0.635	-	-	-	-
Difference with White, 2015-2018	−7.54 (−13.02 to −2.06)	0.009	−0.97 (−6.48 to 4.55)	0.722	-	-	-	-
Change in difference with White, 1999-2018	−0.97 (−8.67 to 6.74)	0.803	−2.75 (−10.06 to 4.55)	0.453	-	-	-	-
Use of antihypertensive medications								
Change in prevalence, 1999-2018	+3.02 (−9.08 to 15.11)	0.616	+18.16 (5.35-30.96)	0.007	+15.11 (6.08-24.13)	0.001	+13.32 (6.69-19.94)	<0.001
Difference with White, 1999-2002	+13.36 (2.93-23.79)	0.001	−25.48 (−34.97 to −16.00)	<0.001	-	-	-	-
Difference with White, 2015-2018	+1.24 (−11.30 to 13.79)	0.841	−23.19 (−38.90 to −7.48)	0.005	-	-	-	-
Change in difference with White, 1999-2018	−12.09 (−28.21 to 4.03)	0.138	+3.05 (−14.61 to 20.71)	0.731	-	-	-	-
Use of antihyperglycemic medications								
Change in prevalence, 1999-2018	+4.42 (−8.13 to 16.98)	0.479	+8.25 (−1.79 to 18.28)	0.104	+6.27 (−0.09 to 12.64)	0.053	+6.27 (1.16-11.39)	0.017
Difference with White, 1999-2002	+13.79 (1.46-26.11)	0.030	+2.29 (−4.62 to 9.21)	0.502	-	-	-	-
Difference with White, 2015-2018	+12.07 (4.66-19.47)	0.002	+3.89 (−6.57 to 14.35)	0.452	-	-	-	-
Change in difference with White, 1999-2018	−1.85 (−16.07 to 12.37)	0.795	+1.98 (−10.19 to 14.14)	0.746	-	-	-	-

Continued on the next page

TABLE 2 Continued

	Black Individuals Percentage Points (95% CI)	*P* Value	Hispanic Individuals Percentage Points (95% CI)	*P* Value	White Individuals Percentage Points (95% CI)	*P* Value	Total Percentage Points (95% CI)	*P* Value
Use of lipid-lowering medications								
Change in prevalence, 1999-2018	+30.49 (22.18-38.79)	<0.001	+20.83 (11.45-30.21)	<0.001	+23.78 (15.22-32.34)	<0.001	+23.25 (16.75-29.75)	<0.001
Difference with White, 1999-2002	−7.86 (−17.49 to 1.77)	0.106	−18.36 (− 25.59 to −11.13)	<0.001	-	-	-	-
Difference with White, 2015-2018	−0.56 (−8.22 to 7.09)	0.882	−20.74 (− 29.96 to −11.52)	<0.001	-	-	-	-
Change in difference with White, 1999-2018	+6.71 (−5.42 to 18.83)	0.272	−2.95 (−14.52 to 8.62)	0.611	-	-	-	-

P values for comparisons between 1999-2002 and 2015-2018 were calculated using weighted two-sample *t*-tests for proportions. Trend *P* values were derived from weighted linear regression analyses, incorporating NHANES survey design and weights to assess changes from 1999 to 2018.

HDL-C = high-density lipoprotein cholesterol.

2015 to 2018, compared with the estimated prevalence among White individuals (47.3% [44.6%-50.1%]), the prevalence of MetS among Black individuals was lower by 10.3 percentage points (95% CI: 5.8-14.9; $P < 0.001$) (Table 2).

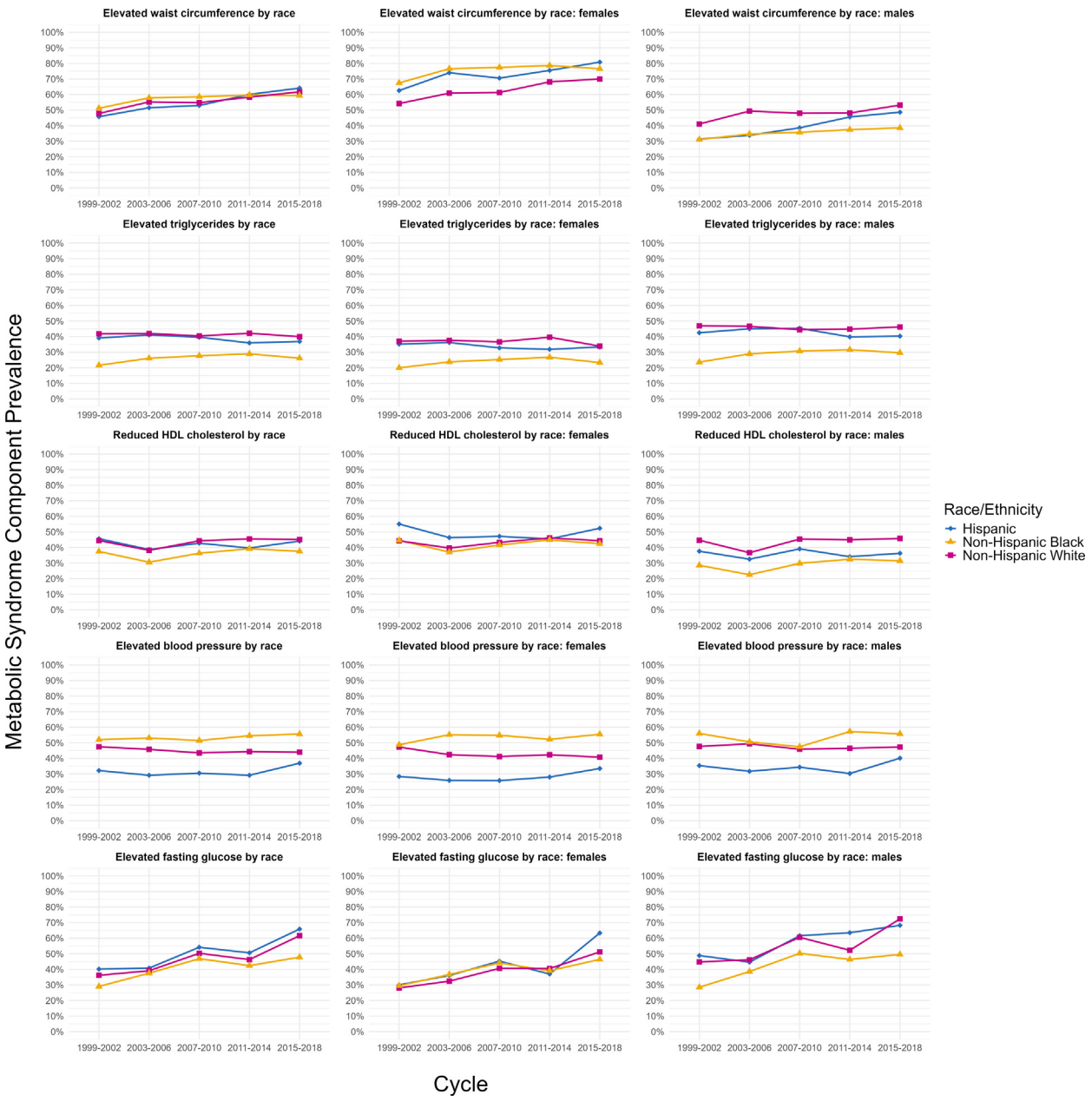
There was a divergence in trends for the individual components of MetS (Figure 2). In 1999 to 2002, compared with White individuals, Black individuals had a significantly higher prevalence of elevated blood pressure ($P = 0.02$), similar prevalence of elevated waist circumference ($P = 0.26$), but lower prevalences of elevated fasting glucose, elevated triglyceride, and reduced HDL-C ($P < 0.05$ for all) (Table 2). These differences between White and Black individuals persisted during the study period. From 1999 to 2018, the age-standardized prevalences of elevated waist circumference and elevated fasting glucose increased significantly for all racial and ethnic groups ($P < 0.01$ for all) (Table 2). The age-standardized prevalences of elevated triglyceride increased among Black individuals ($P < 0.01$) but did not change among Hispanic and White individuals. There was no significant change in the age-standardized prevalence of elevated blood pressure and reduced HDL-C for all racial/ethnic subgroups.

In 2015 to 2018, compared with White individuals, Black individuals had 11.6 percentage points (95% CI: 6.1-17.1; $P < 0.001$) higher prevalence of elevated blood pressure, 13.8 percentage points (95% CI: 9.5-18.1; $P < 0.001$) lower prevalence of elevated fasting glucose, 13.8 percentage points (95% CI: 9.9-17.8; $P < 0.001$) lower prevalence of elevated triglyceride, and 7.5 percentage points (95% CI: 2.1-13.0; $P < 0.01$) lower prevalence of reduced HDL-C. Compared with White individuals, Hispanic individuals had a significantly lower prevalence of elevated blood pressure in 1999 to 2002 ($P < 0.001$). Such a difference persisted during the study period and was 7.1 percentage points (95% CI: 1.7-12.5; $P = 0.01$) in 2015 to 2018.

Figure 3 illustrates the relative prevalence of each MetS component among individuals with MetS compared to all participants, stratified by race/ethnicity. Overall, elevated triglycerides and reduced HDL-C emerged as the primary drivers of MetS, while elevated waist circumference contributed the least. Notably, elevated glucose was a stronger contributor to MetS among Hispanic individuals compared to White individuals, whereas elevated blood pressure played a more significant role among Black individuals than among White individuals.

TRENDS IN TREATMENT OF INDIVIDUAL COMPONENTS OF MetS. In 1999 to 2002, the age-standardized proportion of antihypertensive medication use was

FIGURE 2 Trends in Prevalence of Metabolic Syndrome Components



Age-standardized prevalence of Metabolic Syndrome components in the adult U.S. population. HDL-C = high-density lipoprotein.

64.0% (53.4%-74.6%) for Black individuals, 23.6% (16.6%-30.5%) for Hispanic individuals, and 51.0% (45.4%-56.6%) for White individuals (**Central Illustration**). The differences between White and other subgroups were statistically significant ($P < 0.01$ for each). From 1999 to 2018, the age-standardized proportion of antihypertensive medication use increased significantly for Hispanic and White individuals ($P < 0.01$ for each) (**Table 2**). In the same period, the difference between White and other subgroups did not change significantly. In 2015 to 2018, compared with White individuals (64.8%

FIGURE 3 Relative Contribution of Metabolic Syndrome Components

Relative prevalence of Metabolic Syndrome components among individuals with and without Metabolic Syndrome, overall and by race/ethnicity, 1999-2018. Abbreviation as in Figure 2.

[57.5%-72.1%]), the proportion of antihypertensive medication use among Hispanic individuals was lower by 23.2% (95% CI: 7.5%-38.9%; $P = 0.005$) (Table 2).

In 1999 to 2002, the age-standardized proportion of lipid-lowering medication use was 23.0% (16.2%-29.8%) for Black individuals, 12.3% (6.6%-18.0%) for Hispanic individuals, and 30.5% (25.4%-35.6%) for White individuals (Central Illustration). From 1999 to 2018, the age-standardized proportion of lipid-lowering medication use increased significantly for Black, Hispanic, and White individuals ($P < 0.001$ for each) (Table 2). In the same period, the difference between White and other subgroups did not change significantly. In 2015 to 2018, compared with White individuals (51.7% [46.1%-57.4%]), the proportion of lipid-lowering medication use among Hispanic individuals was lower by 20.7 percentage points (95% CI: 11.5-30.0; $P < 0.001$) (Table 2).

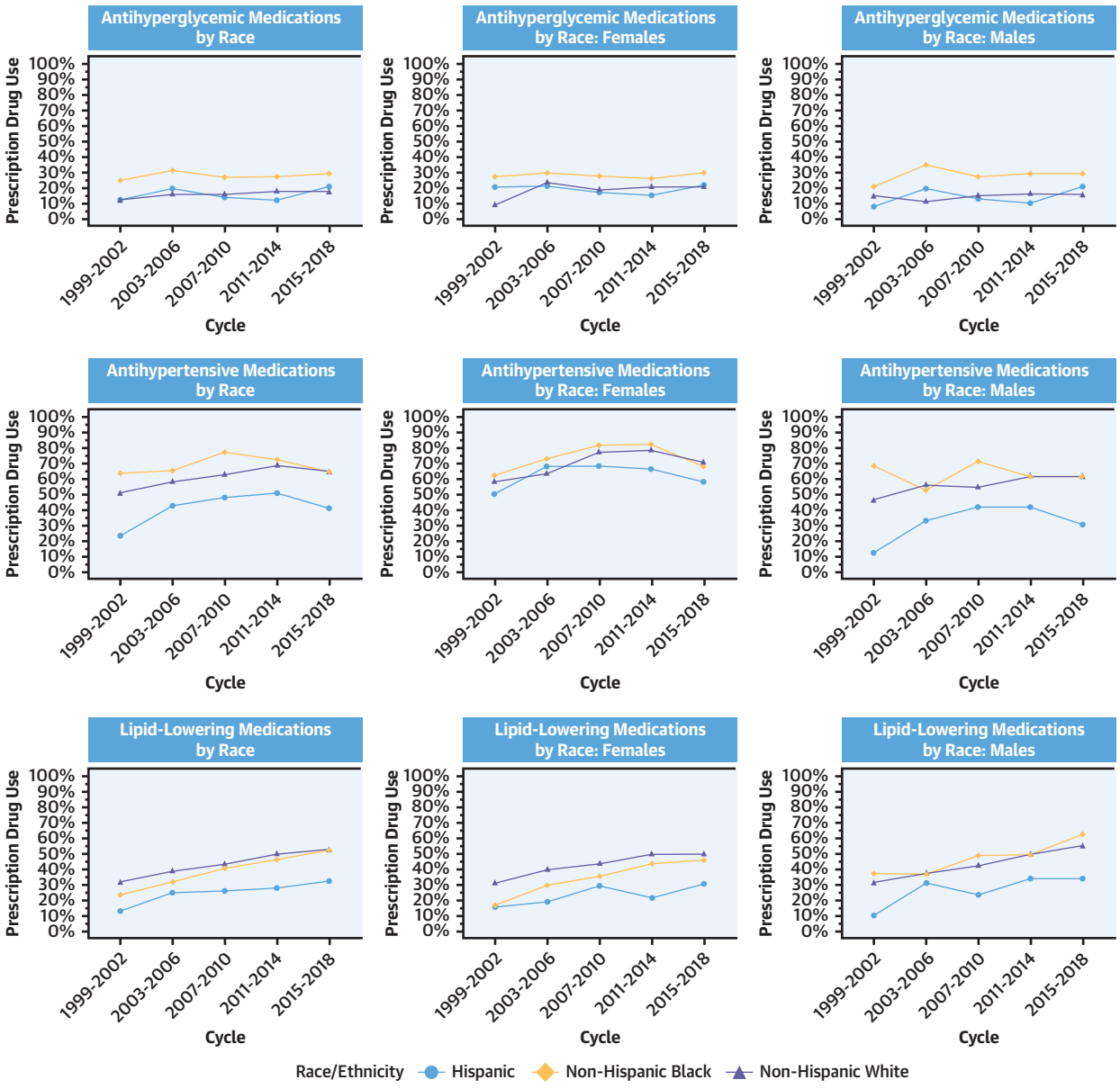
In 1999 to 2002, the age-standardized proportion of antihyperglycemic medication use was 24.5% (13.9%-35.2%) for Black individuals, 12.4% (7.5%-17.3%) for Hispanic individuals, and 11.7% (6.6%-16.8%) for White individuals (Central Illustration). From 1999 to 2018, the age-standardized proportion of antihyperglycemic medication use did not change significantly for all racial/ethnic subgroups (Table 2). In the same period, the difference between White and other subgroups did not change significantly. In 2015 to 2018, compared with White individuals (17.0% [13.3%-20.7%]), the proportion of antihyperglycemic medication use among Black individuals was higher by 12.1% (95% CI: 4.7%-19.5%; $P = 0.002$).

Notably, across all racial/ethnic subgroups, <65% and 35% of people with medication indications received lipid-lowering and antihyperglycemic medications, respectively (Central Illustration).

RELATIONSHIPS BETWEEN INDIVIDUAL COMPONENTS OF MetS. Figure 4 presented the age-standardized Pearson correlations of MetS components in the U.S. adult population. Among Black, Hispanic, and White individuals, the highest Pearson correlation was between elevated triglycerides and reduced HDL-C, with the age-standardized Pearson correlation coefficients ranging between 0.45 and 0.59 ($P < 0.001$ for all). The lowest Pearson correlation for Black individuals was between elevated triglycerides and elevated waist circumference (correlation coefficient = 0.16; $P < 0.001$). The lowest Pearson correlations for Hispanic and White individuals were between elevated blood pressure and reduced HDL-C, with correlation coefficients being 0.13 and 0.21, respectively ($P < 0.001$).

Supplemental Figure 2 presented the change in correlation of MetS components during the study period. From 1999 to 2018, the Pearson correlations between elevated triglycerides and reduced HDL-C and between elevated blood pressure and reduced HDL-C strengthened over time, while the Pearson correlation between the remaining MetS components did not change significantly.

CENTRAL ILLUSTRATION **Trends in Prescription Drug Use for Metabolic Syndrome**



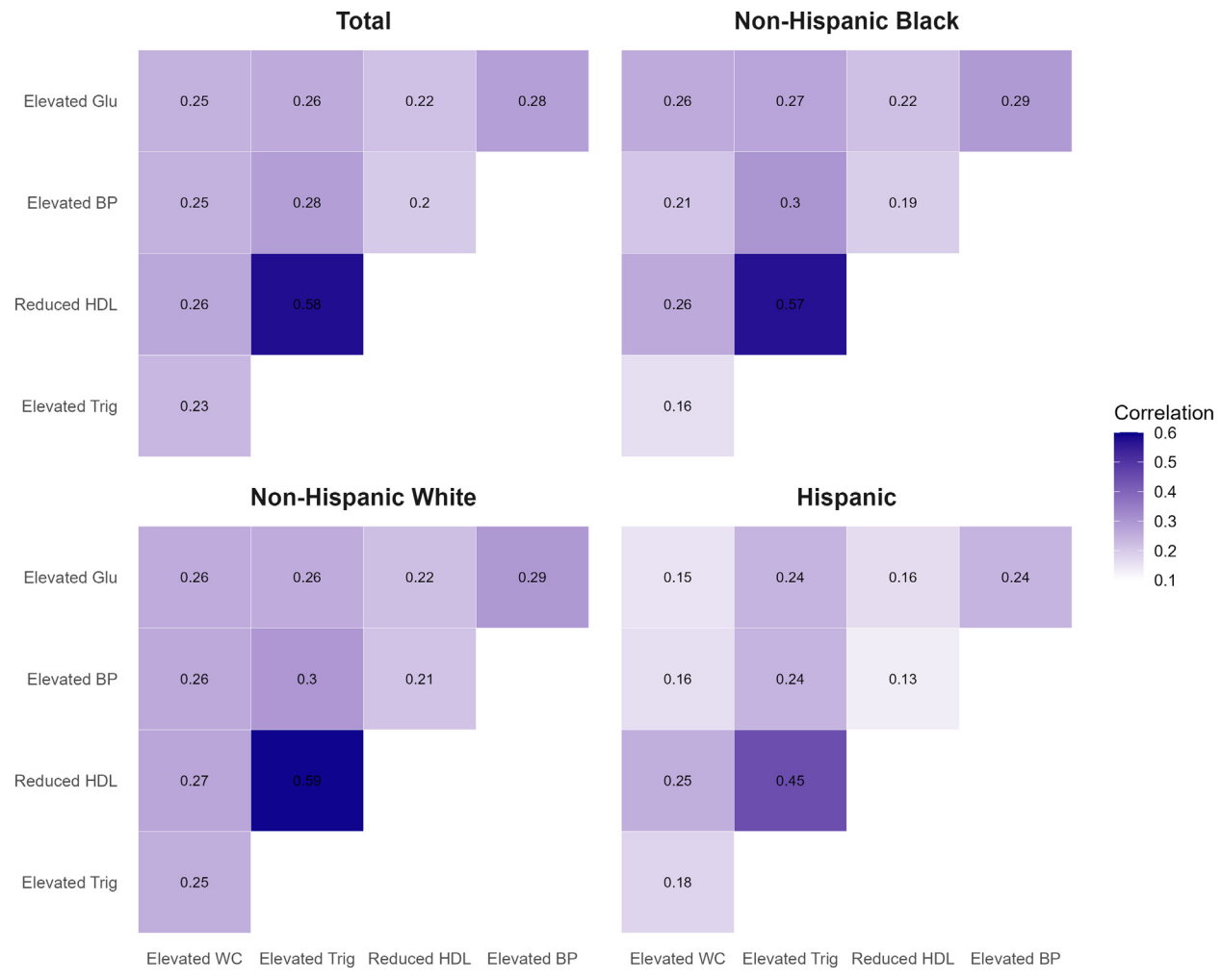
Lu Y, et al. JACC Adv. 2025;4(6):101785.

Age-standardized prevalence of prescription drug use related to components of Metabolic Syndrome in the adult U.S. population.

DISCUSSION

We report nationally representative data of MetS and individual components in U.S. adults from 1999 to 2018. Across this time, the overall prevalence of MetS as well as the prevalences of elevated waist circumference and elevated fasting glucose increased significantly increased for Black, Hispanic, and White individuals. The prevalences of elevated triglyceride increased significantly among Black individuals but did not change among Hispanic and White individuals. The use of lipid-lowering medications

FIGURE 4 Correlations Between Metabolic Syndrome Components



Age-standardized correlations of MetabolicSyndrome components in the U.S. adult population. Elevated BP = elevated blood pressure; Elevated GLU = elevated fasting glucose; Elevated Trig = elevated triglycerides; Elevated WC = elevated waist circumference; Reduced HDL = reduced HDL cholesterol.

increased for all racial/ethnic subgroups with persistent racial/ethnic disparities throughout the 2 decades studied. Compared with White individuals, Black individuals had higher use of antihyperglycemic medications and Hispanic individuals had lower use of antihypertensive and lipid-lowering medications. Across all racial/ethnic subgroups, there remain large opportunities for improvements in treatment strategies among those with medication indications.

This study extends the prior literature in 3 important ways. First, we provide the most up-to-date nationally representative data on trends in MetS prevalence and its components across racial/ethnic groups. Previous studies, such as Moore et al (NHANES 1988-2012), found an increasing trend in MetS, with lower prevalence among Black and Hispanic men compared to White men.[21] Similarly, Beltrán-Sánchez (NHANES 1999-2010) observed higher proportions of elevated blood pressure but lower prevalence of elevated triglycerides and reduced HDL-C among Black individuals.[8] Our findings align with these prior trends while extending the analysis over a more comprehensive 20-year period (1999-2018). Our study also builds on work by Palmer et al (2003-2014),[22] Hirode et al (2011-2016),[23] and Park et al (focused on Korea) [24] by offering a broader

temporal scope and an in-depth examination of racial/ethnic disparities in MetS prevalence, treatment patterns, and interrelationships among its components. Second, we provide a novel assessment of racial/ethnic differences in the treatment of individual MetS components. While prior research has documented overall trends in medication use, detailed quantification of racial/ethnic disparities in treatment remains limited. Our study addresses this gap by systematically analyzing treatment patterns for each MetS component. Third, we examine how the relationships between MetS components evolve over time, a dimension that, to our knowledge, has not been previously described. Understanding these population-level interactions and their longitudinal changes is crucial for interpreting the epidemiological transition and shaping national cardiovascular disease prevention strategies. Unlike individual-level studies that assess causal effects of specific risk factors, our analysis captures broader population dynamics, providing essential insights for public health policy and intervention planning.

There are some differences between our estimates of MetS and the results from other studies, largely due to the different definitions of MetS used in the analysis. For example, using the Adult Treatment Panel criteria, Beltrán-Sánchez et al observed a lower prevalence of MetS than that in our study, and they found that Hispanic individuals had the highest prevalence among all racial/ethnic subgroups.[8] Similarly, using the definitions by the National Cholesterol Education Program, Ford et al[25] and Miller et al[10] also observed a lower prevalence of MetS compared with our study. We used the definition published in the joint scientific statement on MetS,[17] which is consistent with the recent consensus on the clinical definition and categorical cut points for MetS.

This study has important public health implications. First, despite increased public health efforts to promote healthier diets and lifestyles, national-level improvements in metabolic health remain limited.[22,23] As the U.S. population continues to age and other comorbidities increase,[26] the rise in the prevalence of MetS is concerning. Strategies to improve metabolic health such as lifestyle modification and use of medications exist.[27] However, as we showed in this study, <65% and 35% of people with medication indications received lipid-lowering and antihyperglycemic medications, respectively. This underscores the need for innovative implementation strategies to improve the uptake of lifestyle modification and medication use in people with MetS, thereby lowering their risk of developing cardiovascular disease. Importantly, we found persistent racial/ethnic differences in treatment of MetS components, with Hispanic individuals having the lowest of lipid-lowering medications. This suggests that prevention strategies for cardiovascular disease may need to be culturally adapted for minority subgroups at the highest risk. Second, besides the changes in levels of individual MetS components, we also reported secular changes in the associations between these components at the population level. We found that among Black, Hispanic, and White individuals, elevated waist circumference was positively associated with elevated fasting glucose and elevated blood pressure and such associations were consistently observed over time. As obesity continues to increase in the United States, the health implication is that elevated blood pressure and diabetes may become more dominant health challenges. This may call to action on modifying factors that moderate the relationship between obesity, elevated blood pressure, and diabetes (eg, body fat distribution, treatment, diet, physical activity, environmental factors) to mitigate the adverse impact of obesity.[28]

STUDY LIMITATIONS. Our study has several limitations. First, the declining response rates in NHANES and reliance on self-reported data for medication use could introduce recall bias, potentially leading to either overestimation or underestimation of therapy usage. While our approach of combining self-reported data with prescription medication files helps address this issue, some uncertainty in our estimates remains. Second, the data on medication use was self-reported, therefore they may be subject to recall bias. Third, we did not assess the prevalence and treatment of MetS in Asian and other racial subgroups due to insufficient sample size. Fourth, our results of medication use may overestimate the appropriateness of therapy, as elevated fasting glucose or hemoglobin A1c levels can reflect transient changes due to comorbidities or illness rather than chronic dysglycemia. Furthermore, clinical decision-making varies based on individual patient circumstances. Fifth, while we adjusted for age in our analysis, other factors such as sex, race/ethnicity, and socioeconomic status were not included in the model. These variables could influence the observed trends and should be considered in future studies to provide a more comprehensive understanding of the determinants of MetS. Finally, although the joint criterion for MetS indicates that population-specific cutoff values for obesity be used, it remains unclear what

the ideal body mass index cutoff is for non-Hispanic Black or Hispanic people; more work in this area would allow researchers to further refine estimates of the prevalence of MetS by race/ethnicity.

CONCLUSIONS

Temporal trends suggest an increase in prevalence of MetS and improvements in treatment of MetS components by race and ethnicity. There were persistent racial/ethnic disparities in use of antihypertensive, antihyperglycemic, and lipid-lowering medications among people with respective medication indications, with Hispanic individuals having lower use of lipid-lowering medications. Across all racial/ethnic subgroups, there remain large opportunities for improvements in antihyperglycemic and lipid-lowering treatment with <35% and 65% of people with medication indication receiving treatment strategies.

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PERSPECTIVES

COMPETENCY IN MEDICAL KNOWLEDGE: The prevalence of MetS continues to rise in the United States across all racial and ethnic groups, with increasing rates of abdominal obesity and hyperglycemia as key contributors. Despite improvements in the use of lipid-lowering and antihypertensive therapies over the past 2 decades, substantial racial/ethnic disparities in treatment persist. Clinicians should recognize the need for more proactive identification and management of MetS, particularly among underserved populations.

TRANSLATIONAL OUTLOOK: Future research should explore targeted strategies to close the persistent treatment gaps for individuals with metabolic risk factors, especially in Hispanic and Black populations. Implementation science approaches and culturally tailored interventions are essential to improve uptake of evidence-based therapies and reduce cardiovascular risk equitably. Enhanced understanding of evolving relationships between MetS components may also inform more effective risk stratification and intervention.

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KEY WORDS cardiovascular diseases, ethnic groups, health disparities, metabolic syndrome

APPENDIX For a supplemental table and figures, please see the online version of this paper.