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Vitamin D status and prevalence of metabolic syndrome by race and Hispanic origin in US adults: findings from the 2007–2014 NHANES

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Abstract

Background: Vitamin D status has been found to be inversely associated with metabolic syndrome (MetS) in some studies. Vitamin D status varies by race and ethnicity, and the association of MetS with vitamin D status in US adults and by race and Hispanic origin has not been evaluated extensively.

Objectives: We aimed to examine the associations between vitamin D status and MetS overall, and across race and Hispanic origin groups, in a nationally representative sample of US adults who participated in the NHANES from 2007 to 2014.

Methods: The total sample included 8639 adults, ≥20 y of age. Serum vitamin D was measured using a standardized LC-tandem MS method and was categorized using data-driven tertiles. MetS was defined using measured waist circumference, triglycerides, HDL cholesterol, blood pressure, and fasting glucose. Multivariable logistic regression models were fitted [accounting for sociodemographic and lifestyle factors, dietary supplement use, and BMI (in kg/m^2)] to examine

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the associations of serum vitamin D with MetS among adults overall, and by race and Hispanic origin.

Results: Serum vitamin D in the lowest tertile (≤56 nmol/L) was significantly associated with increased odds of MetS compared with the highest tertile (>77.9 nmol/L) (fully adjusted model OR: 1.85; 95% CI: 1.51, 2.27). Inverse associations were noted for all race-Hispanic origin groups: non-Hispanic white (NHW) (OR: 2.24; 95% CI: 1.67, 3.01), non-Hispanic black (OR: 1.56; 95% CI: 1.06, 2.29), and Hispanic (OR: 1.48; 95% CI: 1.03, 2.14) adults.

Conclusions: Lower vitamin D status was significantly associated with MetS among US adults after adjusting for sociodemographic and lifestyle factors, dietary supplement use, and BMI. This finding was noted across all race and Hispanic origin groups, although the strength of the association varied, being strongest for NHW adults. *Am J Clin Nutr* 2022;116:1400–1408.

Keywords

vitamin D status; NHANES; metabolic syndrome; race-ethnicity; insulin resistance; serum vitamin D

Introduction

Metabolic syndrome (MetS), a cluster of risk factors including obesity, dyslipidemia, hypertension, insulin resistance, and hyperglycemia (1–3), is associated with increased risk of chronic diseases (4) and death (5). A higher incidence of cardiovascular disease (CVD), coronary heart disease, and stroke is reported in persons with MetS (6). The prevalence of MetS in adults has increased >35% in the United States, from 25.3% in 1988–1994 to 34.2% in 2007–2012 (7); although the increase was not significant ($P = 0.07$) between 2011–2012 and 2015–2016 (8). Based on NHANES 2015–2016 data, 36.9% of US adults had MetS (9). Furthermore, MetS varied across race-Hispanic origin groups; MetS prevalence for non-Hispanic white (NHW), non-Hispanic black (NHB), non-Hispanic Asian, and Hispanic adults was 37.6%, 30.0%, 26.2%, and 40.4%, respectively (8).

Vitamin D is acquired through exposure to sunlight, diet, fortified foods (e.g., milk), and dietary supplements (10, 11). Vitamin D inadequacy is a public health concern (12). Based on NHANES 2011–2012, ~40% of adults have inadequate vitamin D status using the Institute of Medicine's cutoff (<50 nmol/L) (9, 13–15). The prevalence further varies based on season, geographic location, and race and Hispanic origin (16). The higher prevalence of vitamin D inadequacy noted in NHB adults has been attributed to greater skin pigmentation that inhibits cutaneous synthesis of cholecalciferol, as well as lower consumption of vitamin D and racial differences in vitamin D metabolism (17, 18).

Beyond its role in calcium homeostasis and bone health, vitamin D has received attention for its potential role in preventing CVD and type 2 diabetes mellitus (19). Several studies suggest that individuals with low vitamin D concentrations have a greater risk of heart disease, stroke, hypertension, and diabetes (19–21). Studies have examined the association between hypovitaminosis D and MetS and reported an inverse association between vitamin D status and MetS (1, 2, 22); although not all confirmed this finding (23, 24). Many of these

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studies were conducted in small clinic-based populations or lacked racial-ethnic diversity (22, 23, 25, 26).

The apparent racial-ethnic differences observed in some studies that assessed vitamin D concentrations and MetS have led to the hypothesis that the association between vitamin D status and MetS may differ by race and ethnicity (27). A few studies that assessed ethnic-specific differences in diabetes risk by vitamin D status noted an inverse association in NHW and Mexican-American adults but not in NHB adults (27, 28). Similarly, vitamin D deficiency was associated with a higher risk of fatal stroke in white but not in black adults (18). However, 1 study did not find any racial-ethnic differences in the association between vitamin D and cardiometabolic risk (2). Thus, we conducted an exploratory study to examine the associations between vitamin D status and MetS overall, and across race and Hispanic origin groups, using nationally representative NHANES data.

Methods

NHANES is a series of cross-sectional surveys conducted by the National Center for Health Statistics (NCHS), CDC. The survey uses a complex, stratified, multistage probability design and collects nationally representative data on nutrition and health of the US civilian, noninstitutionalized population. Starting in 1999, NHANES has been continuously collecting and publicly releasing data in 2-y cycles. Participants undergo a detailed in-home interview, followed by a visit to the Mobile Examination Center (MEC) that includes a physical examination, and the collection of biospecimens such as blood and urine. The NCHS Research Ethics Review Board approved the NHANES protocol and participants provided informed consent. Data from 2007–2014 were used in this study; these were the latest data on vitamin D concentrations that were available at the time of analysis. Overall, the response rate for the MEC examination varied from 75.4% in 2007–2008 to 68.5% in 2013–2014 (https://wwwn.cdc.gov/nchs/nhanes/responserates.aspx#response-rates).

Description of variables

MetS.—Data on clinical components of MetS were obtained during an in-person clinical examination at the MEC. During this visit, blood samples were drawn to determine plasma fasting glucose, HDL-cholesterol, and serum triglyceride concentrations, and blood pressure and anthropometry measurements were taken using standard methods (29).

MetS in adults was defined according to the National Cholesterol Education Program-Adult Treatment Panel III (30, 31) as having ≥3 of the following cardiometabolic risk factors: *1*) waist circumference ≥102 cm for males and ≥88 cm for females, *2*) serum triglycerides ≥150 mg/dL, *3*) serum HDL cholesterol <40 mg/dL for males and <50 mg/dL for females, *4*) either systolic blood pressure ≥130 mm Hg or diastolic blood pressure ≥85 mm Hg, and *5*) fasting glucose ≥100 mg/dL (29). Individuals who had a diagnosis for high blood pressure or were using medications for high blood pressure were considered as meeting the criteria for elevated blood pressure. Individuals diagnosed with diabetes or using insulin or oral hypoglycemic medications were considered as meeting the criteria for high blood glucose.

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Vitamin D status.—A fully validated, standardized liquid chromatography-tandem mass spectrometry (LC-MS/MS) method was used to measure 25-hydroxyvitamin D_3 [25(OH)D_3] and 25-hydroxyvitamin D_2 [25(OH)D_2] for all eligible participants who participated in NHANES 2007–2014. Serum vitamin D, i.e., total 25(OH)D, was defined as the sum of 25(OH)D_3 and 25(OH)D_2 (11, 32).

Vitamin D status was examined based on data-driven tertiles. Serum vitamin D concentrations were categorized into ≤33rd percentile, >33rd and ≤67th percentile, and >67th percentile. These corresponded to ≤56, >56 and ≤77.9, and >77.9 nmol/L, respectively.

Other covariates.—Demographic and other covariates were self-reported and included sex, age, race and Hispanic origin, smoking status, and physical activity. Race and Hispanic origin was classified as NHW, NHB, Hispanic, and other. Individuals who reported only 1 race were categorized as persons in that specific race and Hispanic origin. Those reporting >1 race were included in the "other" category. Results for the "other" category are included in the total sample analysis and are not shown separately. Education level was categorized into less than high school, high school graduate or General Educational Development (GED), some college or associate degree, and college and postgraduate.

Total family income ($) received last month for all family members was self-reported. Poverty-to-income ratio (PIR) was computed as the ratio of a family's income to the appropriate poverty threshold for that family's size as established by the US Department of Health and Human Services (33). Five categories of PIR were used for this analysis: <1.00, 1.00–1.99, 2.00–2.99, 3.00–3.99, and ≥4.00. Larger PIRs indicate higher family income per capita. Smoking status was defined as nonsmokers, former smokers, and current smokers from 2 questions: "Have you smoked at least 100 cigarettes in your entire life?" and "Do you now smoke cigarettes?" Physical activity was recoded into 2 categories: meeting physical activity guidelines (i.e., ≥150 min of moderate-intensity physical activity per week or its equivalent) or not meeting physical activity guidelines (34). In addition, season (winter/summer) and dietary supplements used (yes or no) were also included in the analysis. Dietary supplement use was defined as taking any vitamins, minerals, or other dietary supplements in the past month (35).

Analytic sample

In NHANES 2007–2014, 9596 nonpregnant adults aged 20 y and older provided a fasting (≥8 h) blood sample at the MEC (Figure 1). Of these, 957 participants were excluded for the following reasons: 676 had missing values in ≥1 MetS variables, 262 were missing serum vitamin D data, and 19 had missing values on smoking status, physical activity, or education. Participants who had missing values on PIR (n = 680) were kept in the analysis and considered in a missing data category. These exclusions resulted in a final analytic sample of 8639 participants.

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Statistical analyses

All statistical analyses were performed using survey procedures in SAS version 9.4 for Windows (SAS Institute, Inc.). We examined the association of vitamin D status and MetS overall as well as by race and Hispanic origin because of the known association of vitamin D status and race-ethnicity (9, 14) as well as a significant interaction noted in the crude model. Means and percentages of sociodemographic and lifestyle factors (age, sex, physical activity, educational status, smoking, PIR, and dietary supplement use), prevalence of MetS and its components (blood pressure, waist circumference, fasting glucose, HDL-cholesterol, and serum triglyceride concentrations), and vitamin D concentrations were derived overall, by vitamin D status (as tertile groups), and by race and Hispanic origin. One-factor ANOVA was used to test if the means of the continuous variables were equal across vitamin D tertile groups and across race and Hispanic origin groups. The associations of the categorical variables with vitamin D tertile groups and with race and Hispanic origin were examined using the first-order Rao–Scott chi-square test. A P value < 0.05 was considered statistically significant.

Multivariable logistic regression models were fitted to examine the association of serum vitamin D concentration (in tertiles) with the response variable, MetS. The basic model (model 1) was adjusted for season. In addition, model 2 was adjusted for age, sex, physical activity, smoking status, education, and PIR. Model 3 was adjusted for these sociodemographic and lifestyle variables as well as dietary supplement use. The final model (model 4) included residuals of BMI (derived from a linear regression of BMI on waist circumference) to represent variability in BMI that is not explained by waist circumference, in addition to the variables included in model 3.

The models were first fitted to the analytic sample overall and then stratified by race and Hispanic origin. ORs with a 95% CI not including 1.0 were considered statistically significant. The 2-y MEC weights for the fasting subsample were used for all analyses. The complex survey features were incorporated for variance estimation and Taylor Series linearization was used to calculate SEs. Model fit statistics for 1-factor ANOVA [R square, root mean square error (RMSE), F test] and logistic regression models [Akaike information criterion (AIC), Schwarz criterion (SC), and −2 log likelihood] were checked and confirmed.

Results

Table 1 presents participants' sociodemographic, lifestyle, and clinical characteristics, overall and by tertiles of serum total vitamin D concentration. The highest tertile of serum vitamin D (tertile 3) was associated with older mean age, higher education, greater PIR, smoking status, dietary supplement use, and meeting physical activity guidelines. Being in tertile 3 was also generally associated with lower CVD risk factors (lower waist circumference, diastolic blood pressure, fasting glucose, and triglyceride concentrations and higher HDL cholesterol). An inverse association was noted between vitamin D status (tertiles) and the prevalence of MetS and several MetS components (abdominal obesity, hyperglycemia, triglyceridemia) and low HDL cholesterol was more prevalent in lower vitamin D tertiles. Specifically, crude MetS prevalence was 38.5%, 36.5%, and 30.8% in tertile 1, 2, and 3 of serum vitamin D concentrations, respectively. The season-adjusted mean

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± SE vitamin D concentrations were 41.0 ± 0.3, 66.4 ± 0.1, and 97.8 ± 0.6 nmol/L for tertile 1, 2, and 3 of serum vitamin D, respectively.

The distribution of sociodemographic, lifestyle, and clinical characteristics varied across the 3 race and Hispanic origin groups (Table 2). NHW adults were older on average, and more likely to have higher education, family income, and dietary supplement use, and a higher prevalence of meeting physical activity guidelines. NHB adults were more likely to be current smokers, as well as having higher mean systolic blood pressure and HDL-cholesterol concentrations. Hispanic adults had higher fasting glucose ($P = 0.002$) and serum triglyceride concentrations ($P < 0.001$); in addition, they had higher prevalence of reduced HDL cholesterol ($P < 0.001$) and triglyceridemia ($P < 0.001$). The crude MetS prevalence was similar among the 3 race and Hispanic origin groups (range: 34.0–36.7%; $P = 0.13$). The crude and season-adjusted mean vitamin D concentrations were significantly different between the groups, being lowest for NHB adults and highest for NHW adults (P value < 0.001 for all pairwise tests).

The association between serum vitamin D concentrations treated as a categorical variable (tertiles) and MetS, based on logistic regression models, is shown in Table 3, overall and by race and Hispanic origin. The strength of the association varied between various race-Hispanic origin groups; the association was strongest among NHW adults and much weaker for NHB and Hispanic adults. In model 1 (i.e., adjusting for season alone), this association was significant only among NHW adults (OR: 1.95; 95% CI: 1.48, 2.56 for tertile 1 compared with tertile 3) and not in other race and Hispanic origin groups. The association between serum vitamin D concentrations and MetS was stronger after adjusting for sociodemographic and lifestyle variables (model 2), especially for those with serum vitamin D in the lowest tertile (OR: 1.87; 95% CI: 1.55, 2.26) where this association was significant among all race and Hispanic origin groups. These findings were consistent upon further adjustment for the use of dietary supplements both overall (model 3) (OR: 1.89; 95% CI: 1.55, 2.31) and when stratified by race and Hispanic origin (NHW OR: 2.27; 95% CI: 1.69, 3.04; NHB OR: 1.54; 95% CI: 1.05, 2.25; and Hispanic OR: 1.50; 95% CI: 1.05, 2.16).

Finally, model 4 accounting for residuals of BMI (derived from a linear regression of BMI on waist circumference with $R^2 = 0.81$) in addition to all other variables in model 3 showed similar associations between vitamin D and MetS overall (OR: 1.85; 95% CI: 1.51, 2.27) as well as for NHW adults (OR: 2.24; 95% CI: 1.67, 3.01); the association was weaker in NHB and bordering on nonsignificant for Hispanic adults (NHB OR: 1.56; 95% CI: 1.06, 2.29; and Hispanic OR: 1.48; 95% CI: 1.03, 2.14).

Discussion

In a nationally representative sample of US adults, we found a significant inverse association between serum vitamin D and prevalence of MetS overall, and in all race-Hispanic origin groups; the association was stronger among NHW and weaker among other groups, especially among Hispanic adults. This study adds to the limited literature on the association between vitamin D and MetS among adults in the United States (2, 36) and elsewhere (37,

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38). Our findings are important because MetS has been associated with long-term morbidity and mortality (39, 40).

It has been suggested that the association of vitamin D and MetS may be modified depending on whether the analyses adjusted for BMI (in kg/m^2) or another anthropometric index as a proxy for adiposity (41). However, our study did not support this because the association between serum vitamin D and MetS, although attenuated, remained consistent despite adjusting for residuals of BMI.

Several studies have assessed the association of vitamin D with MetS and its individual components. One of the earlier studies using NHANES III data showed that vitamin D concentrations in US adults were inversely associated with the prevalence of MetS ($P < 0.001$) and that this was noted across various racial-ethnic groups examined (36). A population-based study in Japan noted an inverse trend between 25(OH)D and MetS (42); but these findings were not confirmed in a study conducted in Iran (37). Al-khalidi et al. (2) studied the overall and ethnic-specific associations between serum 25(OH)D concentrations and metabolic risk, using NHANES 2001–2010 data. In this study, the authors used inclusion criteria that were similar to those of our study; however, they excluded participants with an estimated glomerular filtration rate (eGFR) < 60 $mL \cdot min^{-1} \cdot 1.73\ m^{-2}$, an indicator of kidney function. eGFR has lately been called into question because of the use of race in its estimation and has become one of the exemplars of the controversy around racial disparity in the medical community (42–45). The eGFR is innately "race-corrected" and higher eGFR levels are often reported among black participants, which has important clinical implications including under-diagnosis and worse health outcomes (42–44). Considering this unsettled debate around using "race-corrected" eGFR, our study did not further exclude participants based on their eGFR levels, because this could have selectively excluded more nonblack participants. In addition, evidence suggests that chronic kidney disease could be a complication associated with MetS (46–48) and thus excluding participants with chronic kidney disease may not be appropriate. Despite this methodological difference, our findings are consistent with those of Al-khalidi et al. (2) who reported an inverse association between 25(OH)D and cardiometabolic disease, which was consistent across race and ethnic background.

Racial differences have been reported in the associations between vitamin D concentrations and certain health outcomes (17, 18, 49, 50). A study in a clinic-based Hispanic population showed that vitamin D status was inversely associated with the risk of MetS (25). The evidence has been most conclusive for bone health with researchers hypothesizing a paradoxical association for NHB persons such that this group has lower circulating vitamin D concentrations in the deficient range and yet has the lowest incidence of falls, fractures, and osteopenia (17, 50). Studies have shown differential racial-ethnic patterns for the associations of vitamin D and other outcomes such as stroke death (18) and diabetes (27), with an association observed only in NHW, but not in NHB adults. On the other hand, the Health, Aging and Body Composition study showed that low vitamin D concentrations were associated with an increase in all-cause mortality for both black and white participants (51). These findings were confirmed by another nested case–control study that concluded that vitamin D concentrations influenced mortality for both African-American and non-African-

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American adults (52). This is generally consistent with the findings observed in the current study where significant negative associations between vitamin D and MetS prevalence were noted for all race-Hispanic origin groups; however, the association was stronger among NHW than in other groups (NHB and Hispanic).

Vitamin D is involved in a breadth of biological actions and may mitigate the risk of MetS in various ways. Insulin resistance is a suspected precursor to MetS and is observed in type 2 diabetes and CVD risk (2, 53). Several studies have shown that decreased vitamin D is associated with insulin resistance and that vitamin D may influence insulin secretion through multiple direct and indirect pathways: *1*) vitamin D binds directly to the β-cell and influences its function (53); or *2*) vitamin D modulates insulin secretion by increasing intracellular calcium concentrations (54). Studies have also shown that low vitamin D may be related to arterial stiffness and vascular dysfunction, both of which are characteristic of hypertension and CVD risk (55). Vitamin D deficiency is thought to stimulate renin expression and inappropriate activation of the renin–angiotensin system may be related to increased risk of hypertension (56).

The study has a few limitations. Vitamin D concentrations and the biomarkers of metabolic health were measured only once and hence any changes over time could not be assessed. NHANES uses a cross-sectional design and the findings do not allow inferences to be drawn regarding direction or causality. Although this study adjusted for potential confounders, the possibility of residual confounding cannot be completely ruled out. Approximately <10% of participants (n = 957) were excluded from the analysis owing to missing values on key variables (MetS components, vitamin D). However, no significant differences were observed in the proportions missing data for MetS components (hypertension, abdominal obesity, low HDL cholesterol, elevated triglycerides, elevated fasting glucose) and serum vitamin D across race-Hispanic origin groups. In addition, in a sensitivity analysis that also included participants with missing data on 1 or 2 MetS components, an additional 78 and 133 participants were identified as having (meeting ≥3 MetS criteria) and not having MetS (not meeting ≥3 MetS criteria), respectively. The key findings of significant inverse associations between vitamin D status (in tertiles) and prevalence of MetS overall and by racial-ethnic group were unchanged. In addition, the findings of the association being stronger in NHW adults and weaker in other groups (NHB and Hispanic adults) were also unchanged. In the current study, we examined the associations of serum vitamin D with MetS among adults overall, and by race and Hispanic origin, and there could be an increased risk of making a type I error owing to multiple testing. Despite these limitations, the external validity of the findings is enhanced by the nationally representative sample, the breadth of variables examined in this study, and the range of sociodemographic diversity in the study population.

In conclusion, our findings support the hypothesis that vitamin D status is inversely related with MetS. Furthermore, this association was noted among all race-ethnicity groups examined, although it was strongest in NHW adults and weaker in NHB and Hispanic adults. In this study, vitamin D status was treated as a categorical variable (i.e., tertiles of serum vitamin D) for ease of interpretation. A sensitivity analysis using vitamin D as a continuous variable showed similar significant inverse associations between vitamin D status and prevalence of MetS overall and by racial-ethnic group (results not shown). Future large

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intervention studies and well-designed observational studies may provide more evidence on whether improving vitamin D status may lower the incidence of MetS.

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Data availability

Data described in the article, code book, and analytic code are publicly and freely available without restriction at https://www.cdc.gov/nchs/nhanes/index.htm.

Abbreviations used:

CVD	cardiovascular disease
eGFR	estimated glomerular filtration rate
MEC	Mobile Examination Center
MetS	metabolic syndrome
NCHS	National Center for Health Statistics
NHB	non-Hispanic black
NHW	non-Hispanic white
PIR	poverty-to-income ratio
25(OH)D_2	25-hydroxyvitamin D_2
25(OH)D_3	25-hydroxyvitamin D_3

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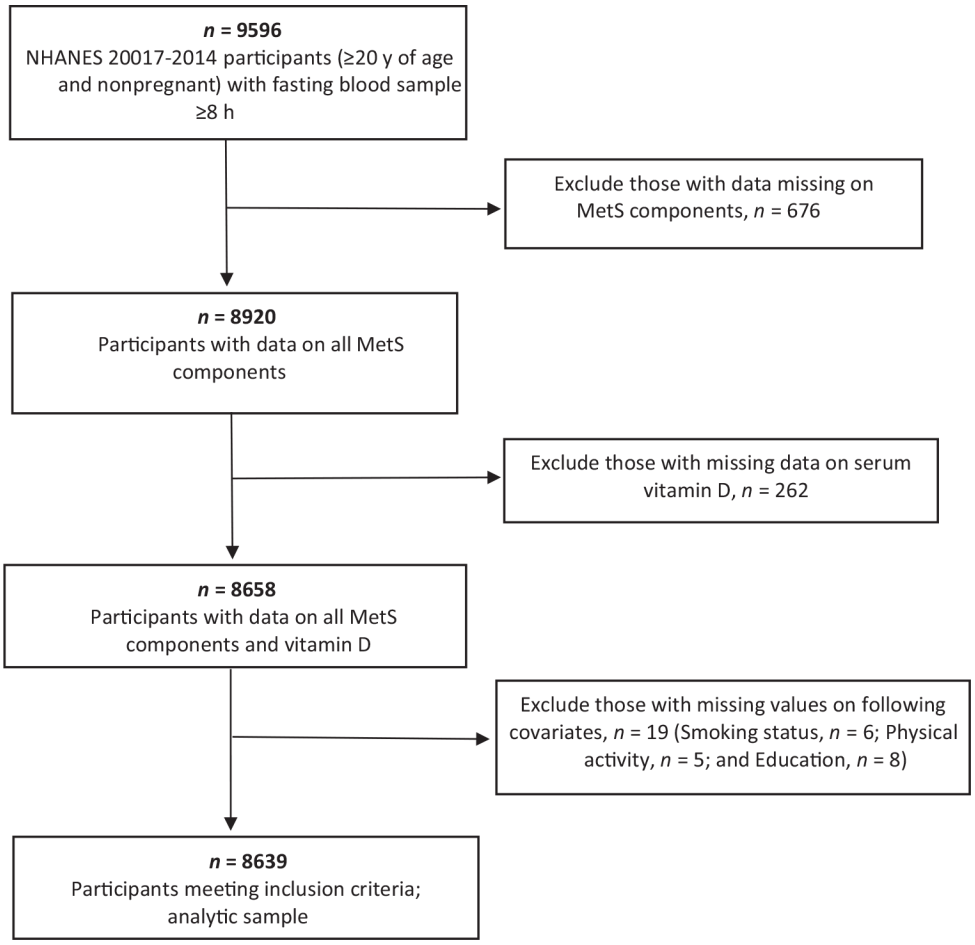

FIGURE 1.

Flowchart describing the sample exclusion criteria used in this study, which uses data from NHANES (2007–2014). MetS, metabolic syndrome.

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TABLE 1

Weighted distribution of sociodemographic, lifestyle, and clinical characteristics by serum vitamin D tertiles in US adults, 2007–2014[1]

Characteristic	Overall (*n* = 8639)		Serum vitamin D tertile, nmol/L			
	Sample size[2]	Mean or % ± SE	1st tertile (≤56) (*n* = 3488), mean or % ± SE	2nd tertile (>56 and ≤77.9) (*n* = 2828), mean or % ± SE	3rd tertile (>77.9) (*n* = 2323), mean or % ± SE	*P* value[3]
Age at screening, y	8639	47.2 ± 0.3	43.6 ± 0.4	46.5 ± 0.4	51.6 ± 0.5	<0.001
Male, %	4242	49.2 ± 0.6	50.3 ± 1.1	56.0 ± 1.3	41.2 ± 1.1	<0.001
Education, %						<0.001
Less than high school	2225	17.7 ± 0.9	21.5 ± 1.0	18.1 ± 1.2	13.5 ± 1.3	
High school graduate or GED	1931	21.7 ± 0.9	23.4 ± 1.4	20.9 ± 1.2	20.8 ± 1.0	
Some college or associate degree	2428	30.5 ± 0.7	30.4 ± 0.9	31.3 ± 1.2	29.8 ± 1.3	
College and postgraduate	2055	30.1 ± 1.2	24.7 ± 1.4	29.8 ± 1.4	35.8 ± 1.8	
Poverty-to-income ratio, %						<0.001
<1	1713	14.1 ± 0.8	19.3 ± 1.4	13.2 ± 0.8	9.9 ± 0.9	
1–2	2117	19.4 ± 0.7	22.8 ± 0.9	19.7 ± 1.0	15.5 ± 1.2	
2–3	1174	14.2 ± 0.7	15.0 ± 1.0	14.2 ± 1.1	13.3 ± 1.1	
3–4	905	13.0 ± 0.7	12.5 ± 1.0	13.9 ± 1.0	12.5 ± 1.2	
≥4	2050	33.4 ± 1.4	24.0 ± 1.5	33.4 ± 1.6	42.6 ± 2.0	
Missing	680	6.0 ± 0.5	6.3 ± 0.6	5.5 ± 0.7	6.1 ± 0.9	
Smoking status, %						<0.001
Nonsmoker	4799	55.8 ± 0.9	57.9 ± 1.3	54.8 ± 1.5	54.7 ± 1.5	
Former smoker	2096	24.5 ± 0.8	18.1 ± 0.7	27.2 ± 1.2	28.2 ± 1.6	
Current smoker	1744	19.7 ± 0.8	23.9 ± 1.2	18.0 ± 1.1	17.2 ± 1.2	
Meeting physical activity guidelines (≥150 min/wk), yes %	2870	37.2 ± 1.1	31.1 ± 1.2	35.5 ± 1.6	44.9 ± 1.8	<0.001
Dietary supplement use, yes %	4263	51.8 ± 0.9	33.2 ± 0.9	50.9 ± 1.2	71.4 ± 1.6	<0.001
WC, cm	8639	98.7 ± 0.3	101.4 ± 0.5	99.1 ± 0.5	95.6 ± 0.5	<0.001
Systolic blood pressure, mm Hg	8639	121.0 ± 0.3	121.2 ± 0.4	120.3 ± 0.5	120.1 ± 0.4	0.14
Diastolic blood pressure, mm Hg	8639	70.0 ± 0.3	70.2 ± 0.3	70.0 ± 0.4	68.8 ± 0.3	0.001
Fasting glucose, mg/dL	8639	105.0 ± 0.5	108.1 ± 0.9	104.6 ± 0.6	102.0 ± 0.6	<0.001
Serum HDL cholesterol, mg/dL	8639	54.0 ± 0.3	51.1 ± 0.3	52.1 ± 0.4	57.6 ± 0.6	<0.001

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Characteristic	Overall (n = 8639)		Serum vitamin D tertile, nmol/L			
	Sample size[2]	Mean or % ± SE	1st tertile (≤56) (n = 3488), mean or % ± SE	2nd tertile (>56 and ≤77.9) (n = 2828), mean or % ± SE	3rd tertile (>77.9) (n = 2323), mean or % ± SE	P value[3]
Serum triglyceride, mg/dL	8639	127.0 ± 1.7	131.3 ± 2.8	129.2 ± 2.5	121.8 ± 2.5	0.02
Metabolic syndrome, yes %	3333	35.2 ± 0.9	38.5 ± 1.5	36.5 ± 1.3	30.8 ± 1.4	<0.001
Total serum vitamin D,[4] nmol/L	8639	68.5 ± 0.7	40.9 ± 0.3	66.6 ± 0.1	98.1 ± 0.5	<0.001
Total serum vitamin D,[4] nmol/L, least-squares mean adjusted for season	8639	67.6 ± 0.5	41.0 ± 0.3	66.4 ± 0.1	97.8 ± 0.6	<0.001
MetS components						
Abdominal obesity (WC ≥102 cm for males, ≥88 cm for females), yes %	4863	55.2 ± 0.9	61.4 ± 1.3	54.3 ± 1.7	49.9 ± 1.4	<0.001
Elevated blood pressure (systolic ≥130 mm Hg, diastolic ≥85 mm Hg, or medication), yes %	3799	39.1 ± 0.9	37.7 ± 1.3	39.0 ± 1.4	40.6 ± 1.4	0.31
Elevated fasting glucose (≥100 mg/dL or medication for diabetes), yes %	4545	48.3 ± 0.9	51.0 ± 1.3	48.4 ± 1.4	45.4 ± 1.1	0.001
Reduced HDL cholesterol (< 40 mg/dL for males and < 50 mg/dL for females), yes %	2476	27.9 ± 0.8	34.6 ± 1.3	28.3 ± 1.2	20.8 ± 1.3	<0.001
Elevated triglycerides (≥150 mg/dL), yes %	2253	25.5 ± 0.7	27.0 ± 1.1	26.9 ± 1.2	22.4 ± 1.3	0.01

[1] Source: NHANES. All estimates except sample sizes are weighted. GED, General Educational Development; WC, waist circumference.

[2] Unweighted sample size in the overall analysis including the Other race-Hispanic origin group. For each continuous variable, n = 8639; for each categorical variable, sample size across all categories is 8639.

[3] P values are for testing independence of vitamin D tertile groups and each categorical variable using first-order Rao–Scott chi-square test, and for testing if means are equal across vitamin D tertile groups for each continuous variable using 1-factor ANOVA (except for the least-squares means).

[4] Total serum vitamin D is the sum of serum 25(OH)D_2 and 25(OH)D_3.

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TABLE 2

Weighted distribution of sociodemographic, lifestyle, and clinical characteristics by race-ethnicity in US adults, 2007–2014[1]

Characteristic	Non-Hispanic white (*n* = 3918), mean or % ± SE	Non-Hispanic black (*n* = 1612), mean or % ± SE	Hispanic (*n* = 2246), mean or % ± SE	*P* values[2]
Age at screening, y	49.2 ± 0.4	44.6 ± 0.5	41.3 ± 0.4	<0.001
Male, %	49.2 ± 0.7	46.6 ± 1.4	52.0 ± 1.0	0.01
Education, %				<0.001
Less than high school	12.6 ± 1.1	20.6 ± 1.4	42.7 ± 1.4	
High school graduate or GED	21.8 ± 1.2	27.3 ± 1.2	20.3 ± 1.2	
Some college or associate degree	31.2 ± 1.1	33.6 ± 1.3	24.9 ± 1.3	
College and postgraduate	34.3 ± 1.7	18.6 ± 1.2	12.1 ± 1.1	
Poverty-to-income-ratio, %				<0.001
<1	9.9 ± 1.1	22.4 ± 1.9	28.4 ± 1.9	
1–2	17.2 ± 1.0	26.5 ± 1.2	25.8 ± 1.2	
2–3	14.6 ± 0.9	13.5 ± 1.2	13.0 ± 1.3	
3–4	14.1 ± 0.9	11.1 ± 1.0	8.3 ± 1.4	
≥4	39.8 ± 2.0	18.7 ± 1.6	12.9 ± 1.1	
Missing	4.4 ± 0.6	7.8 ± 0.9	11.6 ± 1.1	
Smoking status, %				<0.001
Nonsmoker	52.2 ± 1.2	59.9 ± 1.4	64.7 ± 1.4	
Former smoker	28.1 ± 1.0	14.9 ± 0.8	19.2 ± 0.8	
Current smoker	19.7 ± 1.1	25.3 ± 1.2	16.1 ± 1.1	
Meeting physical activity guidelines (≥150 min/wk), yes %	38.2 ± 1.5	35.4 ± 1.4	32.6 ± 1.1	0.002
Dietary supplement use, yes %	56.7 ± 1.1	42.7 ± 1.4	36.0 ± 1.3	<0.001
WC, cm	99.4 ± 0.3	100.1 ± 0.5	98.5 ± 0.6	0.10
Systolic blood pressure, mm Hg	120 ± 0.4	125 ± 0.5	119 ± 0.5	<0.001
Diastolic blood pressure, mm Hg	70 ± 0.3	71 ± 0.4	69 ± 0.4	<0.001
Fasting glucose, mg/dL	104 ± 0.5	106 ± 1.1	108 ± 1.0	0.002
HDL cholesterol, mg/dL	54 ± 0.3	56 ± 0.4	51 ± 0.3	<0.001
Triglyceride, mg/dL	130 ± 2.1	96 ± 2.2	139 ± 4.2	<0.001
Metabolic syndrome, yes %	36.7 ± 1.1	34.0 ± 1.2	34.6 ± 1.3	0.13

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Characteristic	Non-Hispanic white (*n* = 3918), mean or % ± SE	Non-Hispanic black (*n* = 1612), mean or % ± SE	Hispanic (*n* = 2246), mean or % ± SE	*P* values[2]
Total serum vitamin D, nmol/L	75.0 ± 0.7	48.3 ± 1.1	56.9 ± 0.9	<0.001
Total serum vitamin D, nmol/L, least-squares means (adjusted for season)	73.9 ± 0.6	48.6 ± 1.0	57.7 ± 0.8	<0.001
MetS components				
Abdominal obesity (WC ≥102 cm for males, ≥88 cm for females), yes %	56.8 ± 1.0	59.6 ± 1.4	55.3 ± 1.6	0.14
Elevated blood pressure	40.4 ± 1.2	50.4 ± 1.2	27.8 ± 1.4	<0.001
(systolic ≥130 mm Hg, diastolic ≥85 mm Hg, or medication), yes %				
Elevated fasting glucose (≥100 mg/dL or medication for diabetes), yes %	48.6 ± 1.1	45.3 ± 1.5	49.8 ± 1.6	0.13
Reduced HDL cholesterol (<40 mg/dL for males and <50 mg/dL for females), yes %	27.8 ± 1.1	23.3 ± 1.5	32.8 ± 1.1	<0.001
Elevated triglycerides (≥150 mg/dL), yes %	26.4 ± 0.8	13.2 ± 1.0	30.2 ± 1.1	<0.001

[1] Source: NHANES. All estimates except sample sizes are weighted. GED, General Educational Development; WC, waist circumference.

[2] *P* values are for testing independence of race-ethnicity and each categorical variable using first-order Rao–Scott chi-square test, and for testing if means are equal across race-ethnicity for each continuous variable using 1-factor ANOVA (except for the least-squares means).

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TABLE 3

Association of serum vitamin D tertiles with metabolic syndrome in US adults, 2007–2014[1]

	Overall (*n* = 8639)				
Serum vitamin D teitile	**Sample size[2]**	**OR (95% CI)**	**Non-Hispanic white (*n* = 3918), OR (95% CI)**	**Non-Hispanic black (*n* = 1612), OR (95% CI)**	**Hispanic (*n* = 2246), OR (95% CI)**
Model 1[3]					
Tertile 1	3488	1.44 (1.19, 1.74)	1.95 (1.48, 2.56)	0.79 (0.58, 1.09)	1.10(0.81, 1.50)
Tertile 2	2828	1.30(1.08, 1.56)	1.45 (1.16, 1.81)	0.97 (0.68, 1.40)	0.86(0.63, 1.17)
Tertile 3	2323	Ref	Ref	Ref	Ref
Model 2[4]					
Tertile 1	3488	1.87 (1.55, 2.26)	2.27 (1.72, 3.00)	1.47 (1.03, 2.11)	1.50(1.06, 2.11)
Tertile 2	2828	1.54 (1.25, 1.89)	1.63 (1.26, 2.11)	1.47 (0.99, 2.19)	1.08 (0.78, 1.49)
Tertile 3	2323	Ref	Ref	Ref	Ref
Model 3[5]					
Tertile 1	3488	1.89 (1.55, 2.31)	2.27 (1.69, 3.04)	1.54 (1.05, 2.25)	1.50(1.05, 2.16)
Tertile 2	2828	1.54 (1.25, 1.91)	1.63 (1.25, 2.12)	1.49 (0.99, 2.24)	1.08 (0.77, 1.51)
Tertile 3	2323	Ref	Ref	Ref	Ref
Model 4[6]					
Tertile 1	3488	1.85 (1.51, 2.27)	2.24 (1.67, 3.01)	1.56(1.06, 2.29)	1.48 (1.03, 2.14)
Tertile 2	2828	1.53 (1.24, 1.90)	1.62(1.24, 2.11)	1.54 (1.02, 2.33)	1.08 (0.77, 1.51)
Tertile 3	2323	Ref	Ref	Ref	Ref

[1] Source: NHANES. Serum vitamin D tertiles are based on weighted results and tertiles 1–3 correspond to ≤56, 56 to ≤77.9, and >77.9 nmol/L, respectively. Ref, reference group.

[2] Unweighted sample size in each tertile group in the overall analysis including the Other race-Hispanic origin group.

[3] Model 1: basic model, adjusted for season only.

[4] Model 2: basic model plus sociodemographic and lifestyle factors [season (summer/winter), age (y), meeting physical activity guidelines (yes/no), sex, smoking status (current, former, or nonsmoker), education (less than high school, high school graduate or General Educational Development, some college or associate degree, and college and postgraduate), poverty-to-income ratio (<1, 1–2, 2–3, 3–4, ≥4)].

[5] Model 3: basic model plus sociodemographic and lifestyle factors plus dietary supplement use (yes/no).

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[6] Model 4: basic model plus sociodemographic and lifestyle factors and dietary supplement use (yes/no) plus BMI residuals. BMI residuals were derived from linear regression of BMI on waist circumference ($R^2 = 0.81$).