Vitamin D Status Is a Biological Determinant of Health Disparities

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ABSTRACT

Background In human beings, dark skin requires more exposure to ultraviolet light to synthesize the same amount of vitamin D as lighter skin. It is has been repeatedly shown that at the latitude of the United States there are vitamin D disparities related to skin color. Although inadequate vitamin D status and health disparities have been associated with many of the same diseases, neither nutrition policy nor public health policy in the United States currently recognizes any role at all for vitamin D as a determinant of health disparities.

Objective This study investigated the relationship between health, skin color, and vitamin D nutriture in the US population.

Design The design is cross-sectional, correlational, and can be generalized to the population of the United States.

Participants We used data from 12,505 (unweighted) subjects (3,402 non-Hispanic blacks, 3,143 Mexican Americans, and 5,960 non-Hispanic whites), aged 13 years or older, from the continuous National Health and Nutrition Examination Survey 2003-2006.

Main outcome measure Self-rated health, a repeatedly validated indicator of objective health status, was used as a continuous measure of health.

Statistical analyses performed Using software appropriate for the complex survey design of the National Health and Nutrition Examination Survey, the study consisted of six regression models, one predicting vitamin D status and five predicting self-rated health.

Results Controlling for the covariates sex, interview language, country of birth, tobacco use, age, body mass index, and leisure exercise as well as the socioeconomic variables education and family income, remaining disparities in self-rated health are greatly reduced or eliminated by controlling for serum 25-hydroxyvitamin D levels.

Conclusions We found that socioeconomic factors are the strongest determinant of skin-color based health disparities in the US population, but that it may not be possible to eliminate health disparities in the United States without eliminating the skin-color–related disparities in vitamin D nutriture.
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HEALTH DISPARITIES ARE A MAJOR FOCUS OF current public health efforts. One of the four overarching goals of Healthy People 2020, the US government's plan for public health, is to "achieve health equity, eliminate disparities, and improve the health of all groups."[1] Abundant research, including this study, demonstrates that social factors are determinants of health disparities.[2-4] Far fewer studies have investigated biological factors as determinants of health disparities.

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Anthropologists argue that human skin color is an evolutionary adaptation to medium-wave ultraviolet light (UVB).[5-10] At the latitude of the contiguous United States, annual UVB radiation at the earth's surface at the wavelength that maximizes vitamin D synthesis (297 nm)[11] is about half (southern tip of Florida) to one tenth (western Canadian border) as intense as at the equator.[12] Their theory is that dark skin is protective against UVB and is found in population groups that have lived near the equator for many generations. In population groups that migrate to lower UVB areas, skin tones gradually become lighter because individuals in the population with lighter skin have the evolutionary advantage of higher serum vitamin D levels and its associated health benefits. In population groups that migrate back to higher UVB areas, skin tones gradually become darker because individuals in the population with darker skin have the evolutionary advantage of greater protection from UVB and the health benefits as-

sociated with that protection. Anthropologists measure human skin color as a continuous variable, with many shades between very light and very dark. Other scientific disciplines have often used the social construct of race as an explanatory variable, but the continuous physical characteristic of skin color is rarely measured by nonanthropologists.

From a health perspective, this theory implies that health disparities should be expected in all populations that include individuals with diverse skin colors. In high-UVB areas, those with lighter skin should have poorer health. In low-UVB areas, those with darker skin should have poorer health. Moreover, the theory implies that in low-UVB areas, such as the United States, dietetics practitioners could play a central role in eliminating these health disparities by using individual differences in skin color as a factor in optimizing the vitamin D nutriture of the population.

However, the optimal level of serum 25-hydroxyvitamin D (25[OH]D)—the marker used by scientists and health professionals to measure vitamin D status—is currently unclear. One perspective is that the optimal level is the mean level during human evolution. Although that level is difficult to estimate, a recent study found a mean serum 25(OH)D of 46 ng/mL (115 nmol/L) at latitude 4°S in a sample of 60 traditionally living dark-skinned individuals in equatorial Africa.[13] This is between values found in other highly sun-exposed subjects, such as "markedly tanned" lifeguards (mean 64 ng/mL [161 nmol/L] at latitude 39°N[14]) and premier league soccer players of various skin colors (mean 42 ng/mL [104 nmol/L]) at 53°N.[15] The *Dietary Reference Intakes for Calcium and Vitamin D*[16] reports that a mean population serum 25(OH)D level of 20 ng/mL (50 nmol/L) is sufficient for bone health, but that optimal levels for other functions of vitamin D are unknown. According to the document,[16] these functions include both gene regulation and autocrine and paracrine cell signaling in addition to the well-known endocrine signaling that regulates serum calcium, resulting in possible roles in carcinogenesis, cardiovascular disease, diabetes, falls, immune response, neuropsychologic functions, physical performance, and preeclampsia.

The health effects of suboptimal vitamin D were first suggested as the mechanism powering the evolution of human skin color in 1934.[5] Numerous studies have since demonstrated that lower vitamin D levels related to skin color are associated with the severity or prevalence of specific diseases and conditions.[17-20] In 2003, Fuller,[21] an anthropologist, reviewed the research on vitamin D and reframed the theory of the evolution of human skin color as an explanation for health disparities. Harris,[22] Bibuld,[23] and Grant and colleagues[24] investigated the relationship by reviewing the many specific diseases, disorders, and conditions associated with both health disparities and vitamin D deficiency. Egan and colleagues[25] measured the differences in serum 25(OH)D levels among racial groups in the southeastern United States and suggested vitamin D might play a role in overall health disparities, as did Ginde and colleagues,[26] using data representative of the US population (including the same data used in our study), and Peiris and colleagues,[27] using data from the Veterans Affairs Health Care System. Peiris and colleagues[27] were the first to demonstrate a statistically significant relationship between overall health disparities and vitamin D status, using health care costs as the outcome variable.

Using self-rated health rather than health care costs as the outcome measure, we statistically replicated the findings of Peiris and colleagues.[27] Our study is also the first study in the literature to simultaneously assess the effects of socioeconomic status and serum vitamin D levels on health disparities. These relationships were investigated in a data set that can be generalized to the US population using single-question self-rated health as a measure of health status, race/ethnicity as a proxy for skin color, and serum 25(OH)D measurements as an indicator of vitamin D nutriture.

METHODS

Data for this study come from the continuous National Health and Nutrition Examination Survey (NHANES) conducted by the National Center for Health Statistics,[28] which is part of the Centers for Disease Control and Prevention. NHANES data collection protocols were approved by the National Center for Health Statistics Ethics Review Board. Our study was determined to be exempt from review by the Institutional Review Board of Teachers College, Columbia University. The study uses cross-sectional data from two cohorts of the continuous NHANES data, 2003-2004 and 2005-2006. Because data for children were not collected or were missing at a higher rate on some of this study's variables of interest, this study was limited to individuals aged 13 years or older. It was also limited to individuals who described their race/ethnicity as non-Hispanic black (unweighted n=3,402), Mexican American (unweighted n=3,143), or non-Hispanic white (unweighted n=5,960) (total unweighted N=12,505). NHANES includes two other racial/ethnic groups, Other Hispanic and Other non-Hispanic, that were not included in our study because the groups have no obvious relation to skin color. The names of the racial/ethnic groups reported here are those used by NHANES.

Measures

The term "health disparities" refers to the observation that different subpopulations have different levels of health. In our study, the construct of health was measured using a single-question assessment known as self-rated, self-assessed, or self-perceived health. Respondents were asked, "Would you say your health in general is Excellent, Very Good, Good, Fair, or Poor?" Versions of this question have been included in both public health and clinical studies for decades.[29] Self-rated health has repeatedly been shown to be reliable and valid in terms of mortality, morbidity, and use of health care services.[30-32] As a latent or underlying construct, health is continuous. We assumed that individuals who are asked to rate their health using one of five categories understand they are rounding off a rating of their continuous current health status into one of five equal-size levels for measurement purposes. NHANES participants are asked this question twice, first in an in-home questionnaire and again during their visit to a mobile examination center (MEC). Because the question is asked in the MEC on the same day that blood is drawn for biological measures, the answer from the MEC exam was used for our analysis except for the 7.9% of cases missing that data, for which the answer from the in-home questionnaire was substituted, resulting in no missing data for this variable.

Table 1. Variables used to investigate the relationship between health, skin color, and vitamin D nutriture in the US population

Variable	Levels	Measure	Transformations	Source of data	% Missing[a]
Self-rated health		1=Poor 2=Fair 3=Good 4=Very good 5=Excellent	None	Standardized questionnaire	0
Skin color	Dark (Non-Hispanic black) Medium (Mexican American) Light (Non-Hispanic white)[b]		None	Standardized questionnaire	0
Covariates					
Sex	Female Male[b]		None	Standardized questionnaire	0
Interview language	Spanish English[b]		None	Standardized questionnaire	0
Country of birth	Mexico Elsewhere United States[b]		None	Standardized questionnaire	0
Tobacco user[c]	No[b] Yes		None	Standardized questionnaire	8.5
Age		Fractional years	Converted from months. Ages >85 y recoded to 85 y by NHANES[d] to ensure privacy; mean-centered	Standardized questionnaire	0
Body mass index		Index	Mean-centered	Physical measures of height and weight	1.7
Leisure exercise[e]		Thousands of metabolic equivalents per month	Mean-centered	Standardized questionnaire	1.7
Socioeconomic status					
Education	<9th grade 9th-12th grade but no diploma Some college or associate's degree College graduate Still in school High school grad, General Educational Development diploma[b]		"Still in school" is not an identified category in NHANES; it was created rather than imputing data from other categories for respondents with missing data who were aged 13 to 19 y	Standardized questionnaire	0.3
Family income		Income/poverty ratio 0=low, 5=high	Values >5 recoded to 5 by NHANES to ensure privacy; mean-centered	Standardized questionnaire	5.3
Vitamin D					
Serum 25-hydroxy vitamin D		ng/mL	Model 0: none Models 1-5: mean-centered	Serum Diasorin radioimmunoassay	6.5

[a]% missing is before imputation; after imputation there was no missing data on any variable.
[b]Reference level used in the regression models.
[c]Tobacco use was determined using the question, "During the last 5 days, did you use any product containing nicotine including cigarettes, pipes, cigars, chewing tobacco, snuff, nicotine patches, nicotine gum, or any other product containing nicotine?"
[d]NHANES=National Health and Nutrition Examination Survey.
[e]Leisure exercise was measured by self-reported leisure activities converted into thousands of metabolic equivalents (METS) per month using standard NHANES protocols.

The focus of our statistical models was self-described race/ethnicity, which was used as a proxy for skin color. The other explanatory variables were in three sets: covariates, socioeconomic variables, and serum 25(OH)D levels. At one time NHANES analysts advised that serum 25(OH)D data from the years examined in this study were most likely affected by drifts in the assay performance (method bias and imprecision) over time.[33] However, in November 2010, NHANES released an updated serum 25(OH)D data set for these years that adjusts for these drifts. This study used the updated serum 25(OH)D data. Other details about the variables used in this study are shown in Table 1.

Statistical Analysis

NHANES relies on a complex survey design using both clustering and stratification. Because the size of the population and important subpopulations are known at the time of respondent selection, standard errors and CIs of complex survey data are calculated using the probability of a respondent being in the sample.[34,35] Data were analyzed with the statistical program R (version 2.12.2, 2011, R Project) using the Amelia package (developed by James Honaker, PhD; Gary King, PhD; and Matthew Blackwell, PhD; version 1.5-4, 2011), which creates multiple imputed data sets to deal with missing data, and the Survey package (developed by Thomas Lumley, PhD; version 3.25, 2011), which provides methods for analyzing complex survey data.

Five imputed data sets were created with the Amelia package. For each analysis, each of the five data sets was run separately, and then the results were averaged. To maximize the ability of Amelia to make good imputations, 43 additional NHANES variables were included in the data set used by Amelia, including the strata from the complex survey data. Had this study used listwise deletion of cases with missing data, the data set would have been reduced to 8,399 cases, a reduction of 33%.

Sample weights provided with the NHANES data adjust for unequal probabilities of selection (some subpopulations were oversampled) and nonresponse adjustments.[36] NHANES data are collected in an in-home interview followed by a physical examination at a MEC. Typically there is a loss of about 20% between selection of study participants and completion of the in-home interview. An additional loss of about 5% of the original sample occurs between the interview and completion of the MEC exam. However, statistical weights provided with NHANES data adjust for these losses. This study used only data on individuals who completed the MEC exam and, thus, used the MEC weights, which produce unbiased national estimates.

Six regression models were calculated using the Survey package's svyglm function, which performs sampling-weighted least-squares regression.[34] One of these, Model 0, investigates the extent to which the variables in the study influence serum 25(OH)D levels. The other five models predict self-rated health using race/ethnicity as a proxy for skin color and specific sets of the other explanatory variables. Model 1 includes only race/ethnicity. Model 2 also includes the covariate set of variables. Model 3 also includes serum 25(OH)D. Model 4 does not include serum 25(OH)D, but does include the socioeconomic set of variables. Model 5 includes all sets of explanatory variables.

RESULTS

NHANES provides nationally representative estimates. Because the data were analyzed using complex survey techniques, the sample characteristics of this study reflect the US noninstitutionalized population of non-Hispanic blacks, Mexican Americans, and non-Hispanic whites, aged 13 years and older, during the years 2003 through 2006.[34]

Figure 1 portrays the relationship between serum 25(OH)D levels and race/ethnicity. For comparison purposes, the graph also includes a normal distribution based on Luxwolda and colleagues'[13] findings of vitamin D levels in traditionally living dark-skinned individuals in equatorial Africa as the best available estimated distribution of serum 25(OH)D levels during human evolution.[13] The curves in Figure 1 are smoothed density plots. The total area under each line represents 100% of that subpopulation. Both nanograms per milliliter and nanomoles per liter are shown on the *x* axis. Serum levels of 25(OH)D in the NHANES respondents ranged from 2 to 86 ng/mL (5 to 215 nmol/L) (non-Hispanic blacks, 2 to 64 ng/mL [5 to 160 nmol/L]; Mexican Americans, 3 to 68 ng/mL [7.5 to 170 nmol/L]; and non-Hispanic whites, 3 to 86 ng/mL [7.5 to 215 nmol/L]).

In Table 2, Model 0 is a regression predicting serum 25(OH)D levels. Controlling for the variables in the covariate and socioeconomic sets, serum 25(OH)D levels are still significantly lower in non-Hispanic blacks and Mexican Americans than in non-Hispanic whites. Table 2 also shows the results of the five regression models predicting self-rated health. The focus of these analyses is how the regression coefficients for race/ethnicity change from model to model.

These regression coefficients and their 95% CIs are shown in Figure 2 for both subpopulations and all five models. In Figure 2, the *x* axis is in units of self-rated health. At the zero point there are no health disparities between subpopulations. In Model 3, which controls for vitamin D status, the regression coefficients drop about half the distance to zero (from Model 1) for both subpopulations. In Model 4, controlling for the socioeconomic variable set instead of vitamin D status, the regression coefficients drop about two thirds of the way to zero for both subpopulations. These drops provide additional support for the well-established theory that racial health disparities are related to socioeconomic differences. However, in Model 5, which controls for both, the regression coefficients continue to drop—to zero for non-Hispanic blacks and close to zero for Mexican Americans.

DISCUSSION

Comparing Model 3 with Model 4, it appears that socioeconomic factors are stronger determinants of health disparities than vitamin D. However, in a comparison of Model 4 and Model 5, it also appears that socioeconomic and serum 25(OH)D levels are largely independent determinants of health disparities, which suggests that ending socioeconomic disparities will not eliminate health disparities unless disparities in serum 25(OH)D levels are also eliminated. These models also support the theory that lighter human skin colors evolved because individuals with lighter skin had the evolutionary advantage of higher serum 25(OH)D levels (and resulting better health) at latitudes where UVB is less intense than at the equator.

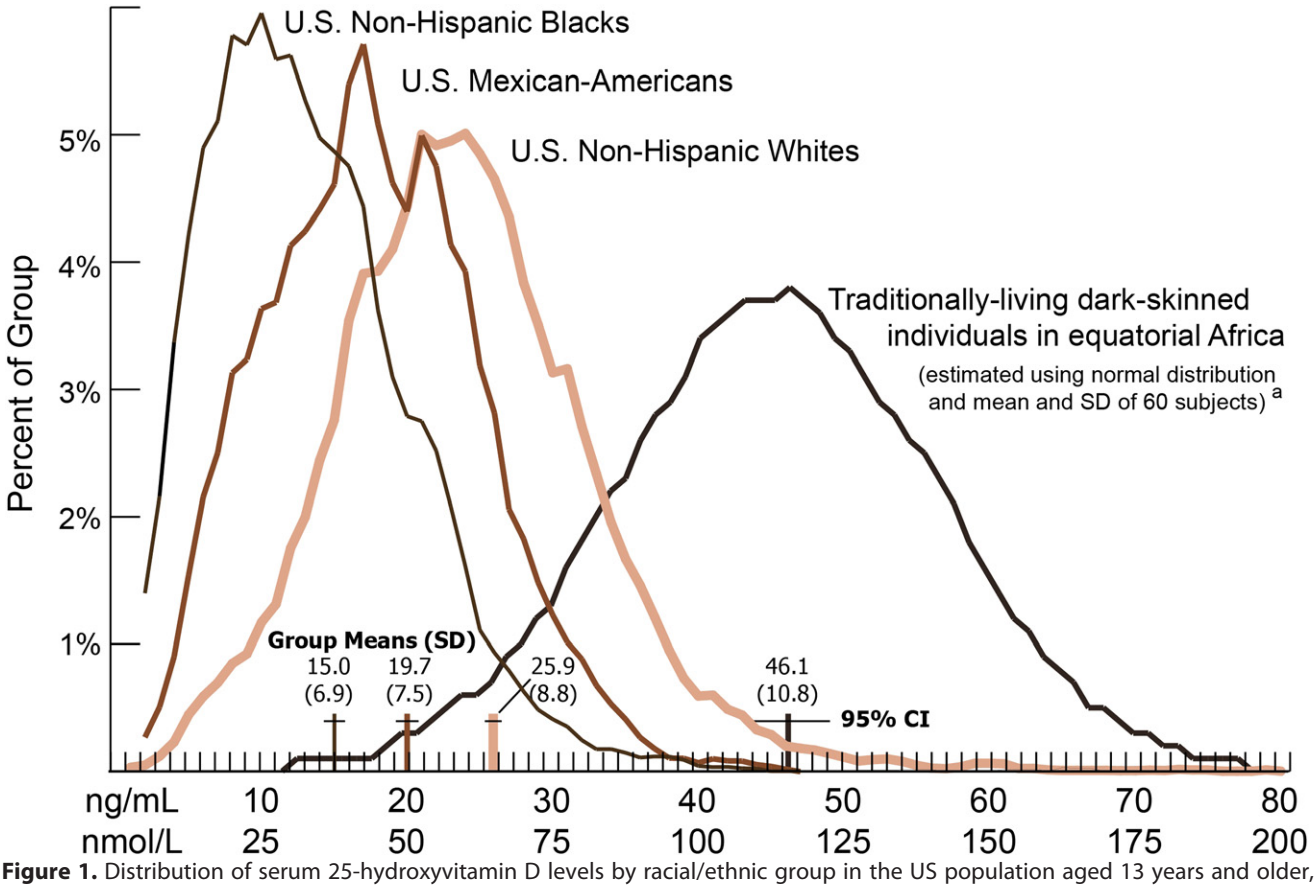

Figure 1. Distribution of serum 25-hydroxyvitamin D levels by racial/ethnic group in the US population aged 13 years and older, 2003-2006, and in dark-skinned, traditionally living peoples in equatorial Africa. Distributions are smoothed by averaging each set of three adjacent data points. The area under each curve represents 100% of that group. Means, standard deviations (SD), and confidence intervals (CI) are shown near the X axis. [a]Data for Africa are from Luxwolda and colleagues[13] and personal communication with the author (May 15, 2012).

Although some of the regression coefficients appear quite small, the continuous variables estimate the health effect of just 1 unit of that factor; for example, 1 year of age or 1 ng/mL (2.5 nmol/L) serum 25(OH)D. In light of this, an increase in serum 25(OH)D of ~10 ng/mL (~25 nmol/L)—the average difference between non-Hispanic blacks and whites—appears to have a health effect equivalent to ~10 years of age.

Vitamin D is unique in that its inactive form is classified as a vitamin, whereas its most physiologically active form—1,25-dihydroxyvitamin D—is classified as a hormone. Consequently, assessing vitamin D nutriture and developing appropriate interventions to optimize vitamin D levels are tasks that may cross several disciplines, including family practice physicians, endocrinologists, pharmacists, and dietetics practitioners. Because of their nutrition assessment skills, dietetics practitioners and clinicians may be the first to suspect vitamin D insufficiency in a client and can recommend that serum 25(OH)D levels be increased. Indeed, dietetics practitioners must assume leadership roles in promoting greater awareness of the prevalence of vitamin D deficiency in large segments of the population, educating both the public health and the health care provider communities on the potentially devastating health effects of untreated deficiency, and providing recommendations for safe, effective, and inexpensive interventions.

Current US public health and nutrition policy related to health disparities and vitamin D can be found in recent major policy updates. Healthy People 2020,[1] the public health plan of the United States, places heavy emphasis on health disparities, includes a goal related to reducing sun exposure, yet does not mention vitamin D. The *Dietary Reference Intakes for Calcium and Vitamin D*,[16] which was released by the Institute of Medicine late in 2010, establishes reference values assuming minimal sun exposure and acknowledges the importance of accounting for biological differences among subpopulations, but reports that "the available data are too limited to permit the committee to assess whether separate, quantitative reference values for such groups are required."[16]

Our study adds to the available data by replicating the health-care-cost findings of Peiris and colleagues[27] using self-rated health and controlling for socioeconomic factors. However, some will object that neither of these studies is a randomized controlled trial; that is, we did not use random assignment to treatment groups from a nonrandom sample of the population. Instead, we used a random sample of the population and nonrandom treatment groups based on skin color. Although we cannot demonstrate causation, randomized controlled trials by other researchers have already shown that specific diseases and conditions are causally related to serum 25(OH)D levels.[16,37,38] Studies like ours, which randomly

Table 2. Predictors of serum 25-hydroxyvitamin D (25[OH]D) status and of self-rated health in the US population aged 13 years old and older, 2003-2006 (unweighted N=12,505)

	Serum 25(OH)D (ng/mL)[a]	Self-Rated Health[b]				
Predictor	**Model 0[c]**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
	← $b \pm SE$[d] →					
Skin color						
Dark (non-Hispanic black)	−10.187±.370***	−.231±.032***	−.231±.027***	−.106±.031**	−.087±.020***	.017±.025
Medium (Mexican American)	−6.387±.678***	−.433±.036***	−.297±.034***	−.216±.033***	−.142±.031***	−.077±.032*
Covariates						
Woman	.240±.212		−.069±.025*	−.071±.025*	−.045±.023	−.047±.023
Interview language Spanish	−.016±.474		−.327±.081**	−.323±.081**	−.118±.081	−.118±.080
Born in Mexico	.750±.593		−.121±.068	−.134±.069	−.052±.077	−.060±.078
Born elsewhere outside the United States	−1.511±.562*		−.007±.059	.010±.058	−.011±.051	.004±.050
Tobacco user	−.677±.327		−.286±.027***	−.278±.028***	−.199±.026***	−.192±.026***
Age (y)	−.041±.008***		−.008±.001***	−.008±.001***	−.008±.001***	−.008±.001***
Body mass index	−.283±.016***		−.027±.002***	−.024±.002***	−.027±.002***	−.025±.002***
Leisure exercise ('000 METS)	.081±.011***		.010±.001***	.009±.001***	.010±.001***	.009±.001***
Socioeconomic variables						
<9th-grade education	.230±.472				−.292±.044***	−.294±.045***
9th- to 12th-grade education, but no diploma	−.484±.388				−.138±.039**	−.133±.040**
Some college or associates degree	−.247±.261				.115±.033**	.118±.033**
College graduate	−.253±.360				.290±.040***	.293±.039***
Still in school	−2.305±.489***				−.079±.040	−.056±.037
Family income	.316±.086**				.092±.006***	.089±.007***
Serum 25(OH)D (ng/mL)[a]				.012±.002***		.010±.002***
Intercept	26.536±.355***	3.505±.025***	3.681±.021***	3.623±.023***	3.494±.032***	3.442±.031***
R^{2}[e]	.234	.021	.132	.142	.192	.200
Wald test[f]	$F(16,14)=230$***	$F(2,28)=72$***	$F(10,20)=159$***	$F(11,19)=171$***	$F(16,14)=189$***	$F(17,13)=165$***

[a]To convert ng/mL serum 25(OH)D to nmol/L, multiply ng/mL by 2.496. To convert nmol/L serum 25(OH)D to ng/mL, multiply nmol/L by 0.401. Serum 25(OH)D of 10 ng/mL=25 nmol/L.
[b]1=Poor; 5=Excellent.
[c]Model 0 predicts serum 25(OH)D and shows that on average, after controlling for the covariate and socioeconomic variable sets, non-Hispanic blacks and Mexican Americans have levels about 10 ng/mL (25 nmol/L) and 6 ng/mL (15 nmol/L) lower than non-Hispanic whites. Models 1 through 5 predict self-rated health with different combinations of the covariate, socioeconomic, and serum 25(OH)D variable sets. The data of interest are the changes in the coefficients for dark and medium skin colors from model to model, which are also shown in Figure 2. The reference group for each variable is shown in Table 1.
[d]SE=standard error.
[e]The percentage of variance that is accounted for by each model is given by R^2.
[f]Complex survey analysis relies on the Wald test as an omnibus test of each model; it takes the place of the analysis of variance test in standard regression.
*$P<0.05$.
**$P<0.01$.
***$P<0.001$.

sample the population, use unrandomized treatment groups, and control for other variables known to affect health, are based on a valid research approach that has been used in the past to set health policy (eg, on the deleterious effects of tobacco).[39]

An important strength of our study is the tight temporal link NHANES provides between vitamin D status, socioeconomic status, and self-rated health. At the latitude of the United States, serum 25(OH)D levels vary by season (there is little to no UVB or bare skin in the winter), which creates problems for research that takes a snapshot of an individual's vitamin D level without regard to season and then tries to associate that level with a health outcome that occurs years later. In the NHANES protocol, blood is collected for 25(OH)D testing on the same day that the respondent provides a self-rated health measurement, ensuring that the serum 25(OH)D level and the self-rated health measurement are connected to each other. This is particularly important because the MECs are not spatiotemporally randomized.[40] This spatiotemporal bias adds unaccounted error to the data in Figure 1. But this

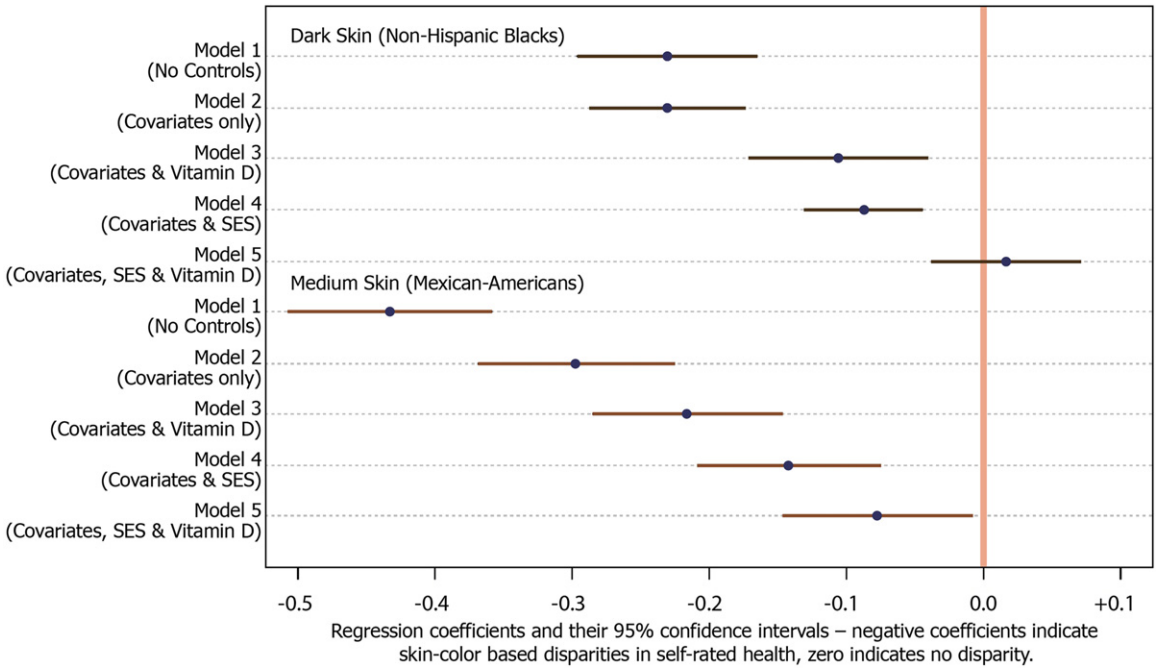

Figure 2. Regression coefficients predicting self-rated health for individuals with dark (non-Hispanic blacks) and medium (Mexican Americans) skin colors, showing 95% CI. The reference group is light skin color (non-Hispanic whites)—a coefficient near zero reflects no disparities in self-rated health by skin color. The covariate variable set includes sex, interview language, country of birth, tobacco use, age, body mass index, and leisure exercise. The socioeconomic variable set includes education and family income. The vitamin D variable set includes only serum 25-hydroxyvitamin D levels. The drop in the regression coefficients towards zero (no disparities) as variable sets are added to the models suggests that socioeconomic status and serum 25-hydroxyvitamin D levels are major determinants of health disparities.

bias has no effect in the regression models that use serum 25(OH)D levels to predict self-rated health, because all the data are collected on the same day for each respondent. On the other hand, our study provides no information on the influence of vitamin D or socioeconomic status on health at any other time than the present (eg, during gestation or childhood).

Another advantage of using self-rated health as a measure of health status is its breadth. Vitamin D deficiency has an effect on a large number of biochemical systems as well as on the regulation of genes and, consequently, may be related to many very different health conditions.[37] A self-rated health score provides a way to capture all of these influences at once. The more typical approach of studying health disparities in terms of a single disease at a time cannot provide self-rated health's overarching view, which is ideal for a subject area that encompasses as many diseases, disorders, and conditions as health disparities. Importantly, this high-level view provides a method to balance any negative effects of vitamin D against its positive effects—a type of balance that studies of single diseases cannot provide. A final advantage of self-rated health is that it supplies a method to compare the relative influence of vitamin D and socioeconomic status on health.

This study also has limitations. Some researchers have found that self-rated health may vary by culture or socioeconomic status.[41,42] We included interview language and country of birth in the covariate set of variables to control for cultural differences in how the subpopulations answer the self-rated health question. The inclusion of these variables accounts for the large drop in the regression coefficient for Mexican Americans between Model 1 and Model 2 (note that the coefficient for non-Hispanic blacks does not change between these two models). However, it is possible that these variables do not capture all of the cultural differences and that the Model 5 regression coefficient for Mexican Americans, like the one for non-Hispanic blacks, might have dropped to zero if they did. As for socioeconomic differences, Dowd and colleagues[42] found that those in higher socioeconomic groups were healthier according to biomarkers than their self-ratings would indicate. This implies that socioeconomic status may be even more important to health disparities than found in this study. A reasonable follow-up study would use biomarkers of health rather than self-ratings to avoid the problems of cultural and socioeconomic differences in how subpopulations respond to the self-rated health question.

There is no measure of skin color in NHANES. Therefore, race and ethnicity— categorical social constructs—are used as proxies for skin color, a continuous biological characteristic. Although it is obvious that race/ethnicity is a reasonable proxy for skin color in the groups used in this study, it would be preferable to use a skin-color measure that captured the great variety of skin shades in the United States rather than race/ethnicity. Finally, using serum 25(OH)D as an indicator of vitamin D nutriture may ultimately be problematic. Although the serum 25(OH)D level is a widely used indicator of exposure, it may not be a good indicator of effect, because it may not reflect autocrine or paracrine activity within tissues and cells that are capable of synthe-

sizing the activated form of vitamin D, such as the pancreas, colon, adrenal glands, and monocytes.[43]

CONCLUSIONS

Our study supports the hypothesis that—after controlling for covariates and socioeconomic factors—skin-color–related disparities in serum 25(OH)D levels are a biological determinant of health disparities in the United States. Disparities in vitamin D status alone seem to account for about half of the effect of racial health disparities. Disparities in socioeconomic status alone seem to account for about two thirds of the effect. Together, vitamin D and socioeconomic disparities appear to be largely independent determinants of health disparities. Our study also supports the hypothesis that the lighter end of the spectrum of human skin color evolved to optimize vitamin D levels in human beings living in geographic areas with lower intensities of UVB than are found near the equator.

Although additional research will be required, this study suggests that the disparities by skin color in the vitamin D status and in the health of the US population are related to each other. Treating groups at risk for insufficient vitamin D—including all people of color living in the United States—with inexpensive vitamin D supplements may be a viable strategy for reducing health disparities and lowering the cost of health care. Our findings suggest that US public health authorities may never eliminate health disparities without attending to the skin-color related disparities in vitamin D nutriture.

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STATEMENT OF POTENTIAL CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

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