Title

Sun-Exposed Skin Color Is Associated with Changes in Serum 25-Hydroxyvitamin D in Racially/Ethnically Diverse Children.

Journal

The Journal of Nutrition, 146(4)

Authors

Sawicki, Caleigh

Van Rompay, Maria

Au, Lauren

et al.

Publication Date

2016-04-01

DOI

10.3945/jn.115.222505

Peer reviewed

The Journal of Nutrition
Nutritional Epidemiology

Sun-Exposed Skin Color Is Associated with Changes in Serum 25-Hydroxyvitamin D in Racially/Ethnically Diverse Children[1,2]

Caleigh M Sawicki,[3]* Maria I Van Rompay,[3] Lauren E Au,[4] Catherine M Gordon,[5] and Jennifer M Sacheck[3]

[3]Friedman School of Nutrition Science and Policy, Tufts University, Boston, MA; [4]Nutrition Policy Institute, University of California, Agriculture and Natural Resources, Berkeley, CA; and [5]Divisions of Adolescent Medicine and Endocrinology, Hasbro Children's Hospital, Alpert Medical School of Brown University, Providence, RI

Abstract

Background: UVB light from the sun increases serum 25-hydroxyvitamin D [25(OH)D] concentration, but this relation may depend on skin pigmentation among different racial/ethnic groups.

Objective: We used quantitative measures of exposed (facultative) and unexposed (constitutive) skin color to examine relations between serum 25(OH)D concentration, tanning, race/ethnicity, and constitutive skin color over the summer, following winter vitamin D supplementation.

Methods: The subjects ($n = 426$, mean age 11.7 ± 1.4 y, 51% female) were racially/ethnically diverse schoolchildren (57% non-white/Caucasian) enrolled in a 6-mo vitamin D supplementation trial (October–December to April–June). In this secondary analysis, measures of serum 25(OH)D concentration and skin color, with the use of reflectance colorimetry, were taken over a 6-mo period after supplementation, from pre-summer (April–June) to post-summer (September–December). Multiple linear regression was used to evaluate longitudinal relations.

Results: Following supplementation, mean serum 25(OH)D concentration was 29.3 ± 9.5 ng/mL but fell to 25.6 ± 7.9 ng/mL ($P < 0.0001$) by the end of summer. The decrease in white/Caucasian children was less than in black/African American children ($P < 0.01$) and tended to be less than in Hispanic/Latino, Asian, and multiracial/other children ($P = 0.19$–0.50) despite similar changes in sun-exposed skin color among all groups. Tanning was significantly associated with post-summer serum 25(OH)D concentration ($\beta = -0.15$, $P < 0.0001$), as was race/ethnicity ($P = 0.0002$), but the later association disappeared after adjusting for constitutive skin color.

Conclusions: Tanning significantly contributed to serum 25(OH)D concentration over the summer, independent of race/ethnicity, but was not sufficient to maintain serum 25(OH)D concentration attained with supplementation. Much of the variation in serum 25(OH)D concentration between racial/ethnic groups may be explained by skin color. This trial was registered at clinicaltrials.gov as NCT01537809. *J Nutr* 2016;146:751–7.

Keywords: vitamin D, schoolchildren, ethnic groups, skin pigmentation, sun exposure, tanning, colorimetry, dietary supplements

Introduction

Vitamin D has many well established roles in the body for calcium absorption, bone growth and maintenance, muscle strength, immune function, inflammatory response, and regulation of cell proliferation, differentiation, and apoptosis (1). Nutrition research has further shown that vitamin D may be associated with reduced risk of chronic disease such as autoimmune diseases, certain cancers, cardiovascular disease, and diabetes (1). Despite awareness of these potential benefits, vitamin D deficiency, defined by the Institute of Medicine as serum 25-hydroxyvitamin D [25(OH)D][6] concentration <12 ng/mL, remains common, including in children and adolescents (1–5).

Vitamin D does not occur naturally in many foods, and even with fortification of certain foods, such as milk and ready-to-eat breakfast cereals, the majority of vitamin D for most people is obtained through synthesis in the skin with exposure to UVB

[1] Supported by the National Heart, Lung, And Blood Institute of the NIH under grant R01HL106160.
[2] Author disclosures: CM Sawicki, MI Van Rompay, LE Au, CM Gordon, and JM Sacheck, no conflicts of interest.
*To whom correspondence should be addressed. E-mail: caleigh.sawicki@tufts.edu.

[6] Abbreviations used: DDHS, Daily D Health Study; ITA, individual typology angle; vitamin D_3, cholecalciferol; 25(OH)D, 25-hydroxyvitamin D; 25(OH)D_2, 25-hydroxyergocalciferol; 25(OH)D_3, 25-hydroxycholecalciferol.

Manuscript received August 12, 2015. Initial review completed September 15, 2015. Revision accepted January 15, 2016.
First published online March 2, 2016; doi:10.3945/jn.115.222505.

light (6, 7). When UVB radiation from the sun (approximate wavelength of 280–320 nm) reaches the lower layers of the skin, 7-dehydrocholesterol is converted to pre-cholecalciferol, which is then converted to cholecalciferol (vitamin D_3) (8–10). Vitamin D_3 from this pathway, as well as vitamin D from foods, is then hydroxylated by the liver to 25(OH)D, the form that is considered most reflective of vitamin D status when measured in serum (1).

The amount of pre-vitamin D_3 that is synthesized in the skin is not only dependent on sun exposure but is also highly dependent on skin pigmentation (9). Specifically, the skin pigment melanin can absorb and scatter UVB photons, inhibiting the efficiency of pre-vitamin D_3 synthesis (8). Therefore, individuals with higher amounts of melanin, conferring a darker skin color, would have reduced vitamin D_3 synthesis. This has been examined in studies that compare vitamin D status between different racial/ethnic groups. These studies have shown that racial/ethnic groups that are generally darker skinned have lower 25(OH)D concentrations than groups with lighter skin color living in the same geographic area (11–14). However, using race/ethnicity as a measure of skin color fails to capture the large variation in skin color within racial/ethnic groups and the overlap in skin color between groups (12, 15).

Rather than using race/ethnicity to categorize skin color, a quantitative measure of skin color may be obtained by reflectance colorimetry and can give a measure of both unexposed (constitutive) skin color and exposed (facultative) skin color (15). As constitutive skin color gets lighter, serum 25(OH)D concentration is higher (8, 16). However, it remains unclear whether this is a better predictor of serum 25(OH)D concentration than race/ethnicity (10, 17). In contrast, as facultative skin color gets darker, or tanned, indicating increased sun exposure, serum 25(OH)D concentration should be higher. There are few studies that have evaluated the effect of tanning on serum 25(OH)D concentration (10, 15, 16, 18), and to our knowledge, none have evaluated serum 25(OH)D concentration, tanning, and race/ethnicity together in a longitudinal analysis. The objective of this study was to examine these associations in a racially/ethnically diverse population of urban school children in the northeastern region of the United States.

Methods

Study design. Study subjects were participants in the Daily D Health Study (DDHS), a randomized, double-blind trial examining the effect of vitamin D supplementation on serum 25(OH)D concentration and cardiometabolic risk factors (NCT01537809). Details of the study methodology are described elsewhere (19). Participants (n = 685 at baseline) were supplemented with 1 of 3 possible vitamin D_3 doses (600, 1000, or 2000 IU/d) for 6 mo (n = 556 completed supplementation phase) and followed for an additional 6 mo post-supplementation (n = 487 completed the 6-mo follow-up). The primary outcomes of this trial were the response of serum 25(OH)D concentration to supplementation over 6 mo and any associated changes in cardiometabolic risk factors, specifically blood glucose and serum lipids. For this analysis, we examine data from the nonsupplementation portion of the study period, from the 6-mo or "pre-summer" study visit (April–June, at which point study supplements were discontinued) to the 12-mo "post-summer" (September–December) study visit, for which complete serum 25(OH)D concentration and quantitative measures of skin color were available (n = 426). Serum 25(OH)D concentration, skin color, and anthropometrics were assessed, and questionnaires were administered at each visit. In addition to child assent, informed consent was obtained from parents, and consent forms and study information were made available in English, Spanish, Portuguese, Haitian-Creole, and Chinese. The study protocol was approved by Tufts University's Institutional Review Board.

Subject characteristics. The subjects were schoolchildren in grades 4–8, recruited from 4 urban school districts just north of Boston, Massachusetts (42°N), during October–December of 2011 (wave 1) and October–December of 2012 (wave 2). Exclusion criteria included having rickets, cystic fibrosis, kidney disease, sarcoidosis, irritable bowel syndrome, epilepsy, or HIV/AIDS. Because individuals with diabetes may have altered vitamin D metabolism (20), subjects who were found to have diabetes (n = 4) were also excluded from analyses.

Parents or guardians were asked to report their child's birth date, sex, and race/ethnicity, as well as eligibility for free or reduced-price lunch (as an indicator of socioeconomic status). Race/ethnicity was inquired as one of the following categories: white/Caucasian, black/African American, Mexican/Mexican American, other Hispanic/Latino, Asian/Asian American/Asian Indian, Native American/American Indian, multiracial/ethnic, or other. For the purpose of analysis, these racial/ethnic categories were aggregated into 5 groups: white/Caucasian, black/African American, Hispanic/Latino, Asian, and multiracial/other. Height and weight were measured at baseline, 6 mo, and 12 mo, and BMI was calculated and then expressed as a z score according to the US Centers for Disease Control sex-specific growth charts (21). Pubertal status was determined at baseline and 12 mo by using a self-administered questionnaire (22).

Dietary intake and sedentary time. The Block Kids 2004 Food Frequency Questionnaire (NutritionQuest) was used to assess dietary intake (23, 24) and has been used previously in a similar population of children (5). FFQ data were considered invalid for subjects who reported a total energy intake of <500 or >5000 kcal/d (25), and these data were excluded from analyses. Daily vitamin D intake was adjusted for total energy by using the residual method. Additionally, at the post-summer time point, subjects were asked if they had taken any vitamin D supplements including multivitamins after the study had stopped providing them and, if so, how often they had taken them in the past week. Physical activity was assessed with the use of the Block Kids Physical Activity Screener (NutritionQuest). Hours of screen time from television, Internet, and video games were used as an estimate of sedentary time and dichotomized: ≥4 or <4 h/d.

Skin color. Quantitative measures of skin color were obtained by reflectance colorimetry with the use of the ChromaMeter 400 (CR-400; Konica Minolta). A measure of constitutive skin color was taken at the upper inner arm, midway between the axilla and medial epicondyle (17). Facultative skin color was measured at the posterior forearm, midway between the olecranon and the ulnar epicondyle, where skin color would consist of both the constitutive skin color and any tanning from sun exposure. Measurements were taken according to an established protocol (10, 15, 26), which further specified that measurements should avoid dense freckling or moles if present and should be repeated 3 times (4 measurements in total) at each site.

Skin color was measured along 2 axes: a lightness-darkness axis and a yellow-blue axis. Based on the mean of 4 measurements and these 2 variables, an individual typology angle (ITA) was calculated as an indicator of skin color ($\mathrm{ITA} = \{[\mathrm{ArcTangent}(L - 50/b)] \times 180/\pi\}$), in which L represents degrees along the lightness-darkness axis, and b represents degrees along the yellow-blue axis) (27). Higher values of ITA correspond to lighter skin. The reliability of the ChromaMeter skin color readings has been verified in this study population previously (17). Tanning was calculated as the change in facultative skin color between pre-and post-summer time points.

Serum 25(OH)D. Blood was drawn after an overnight fast by trained phlebotomists, and samples were processed and stored at −80°C until analysis at Boston University Medical Center. Serum total 25(OH)D was measured by using LC-MS/MS on a TSQ Quantum Ultra triple mass spectrometer (Thermo Finnigan Corp.). This method included fractionation of 25-hydroxyergocalciferol [25(OH)D_2], 25-hydroxycholecalciferol [25(OH)D_3], and epimer of 25(OH)D_3 in serum (28). 25(OH)D_3 and 25(OH)D_2 calibration control solutions were generated from standards provided by Calbiochem. Samples from study subjects were prepared and analyzed through a turbulent flow LC system (Cohesive Technologies) followed by traditional laminar flow chromatography. Study samples were analyzed relative to vitamin D standard references

(National Institute of Standards and Technology), and the intra-assay (within-batch) coefficient of variation is 6.0%. Total 25(OH)D was calculated as the sum of the 25(OH)D_3 and 25(OH)D_2 components.

Statistical analysis. Differences between racial/ethnic groups were compared by chi-square tests for categorical variables and ANOVA with Tukey's honestly significant difference test for continuous variables. Differences in serum 25(OH)D concentration and facultative skin color from pre- to post-summer were tested by paired *t* test. To examine the effects of tanning on serum 25(OH)D concentration over the summer months, longitudinal analysis using multiple linear regression was performed. In the first model, we used post-summer serum 25(OH)D concentration as the dependent variable and tanning (change in facultative skin color) as the independent variable, adjusting for pre-summer serum 25(OH)D concentration. The second model was additionally adjusted for race/ethnicity. Model 3 was additionally adjusted for constitutive skin color in order to assess the extent to which any racial/ethnic differences may be due to differences in genetic skin color. All regression models controlled for age, sex, BMI *z* score, energy-adjusted vitamin D intake, sedentary time, free or reduced-price lunch eligibility, pubertal status, and any reported vitamin D supplement use following the study supplement intervention. At the post-summer time point (September–December), 426 subjects had complete data for serum 25(OH)D, skin color measures, race/ethnicity, and all covariates used in the present analyses. A P value of < 0.05 was considered statistically significant. Data were analyzed with the use of SAS version 9.3 (SAS Institute).

Results

Table 1 shows the study population characteristics. The mean age was 11.7 y, 51% were female, and 57% were from racial/ethnic minority groups (11% black/African American, 22% Hispanic/Latino, 8% Asian, and 15% multiracial/other). Nearly half (45%) of the children were overweight or obese. Mean serum 25(OH)D concentration before supplementation was 22.2 ± 6.9 ng/mL (data not shown) and increased to 29.3 ng/mL at the end of the supplementation intervention (pre-summer). At post-summer (following the discontinuation of supplementation), mean 25(OH)D concentration declined significantly to 25.6 ng/mL ($P < 0.0001$). When stratified by race/ethnicity, all groups experienced a significant decline ($P < 0.01$ for white/Caucasian, $P < 0.0001$ for all other groups; **Figure 1**A); however, the serum 25(OH)D concentration decreased less in white/Caucasian children (2.1 ng/mL) compared with 7.2 ng/mL in black/African American children ($P < 0.01$), 3.9 ng/mL in Hispanic/Latino children ($P = 0.50$), 4.8 ng/mL in Asian children ($P = 0.44$), and 4.8 ng/mL in multiracial/other children ($P = 0.19$; see Table 1 for pairwise comparisons).

Mean constitutive and facultative skin color measurements pre- and post-summer are shown in Table 1. Facultative skin color ITA decreased significantly from pre- to post-summer, reflecting a darkening of the skin, or tanning, over the summer months ($P < 0.0001$, mean of 19.4° and 10.8° at pre- and post-summer, respectively). When stratified by race/ethnicity, all groups experienced a significant decrease in facultative ITA, or significant tanning ($P < 0.0001$ for all groups). As shown in Figure 1B, all racial/ethnic groups tanned to a similar extent, with mean change in facultative ITA of 8.2° for whites/Caucasians, 8.1° for blacks/African Americans, 8.7° for Hispanics/Latinos, 8.8° for Asians, and 9.8° for multiracial/other (overall P value = 0.77).

Table 2 shows the association between post-summer serum 25(OH)D concentration and summer tanning, measured by the change in facultative skin color from pre- to post-summer. In model 1, tanning was significantly associated with post-summer serum 25(OH)D concentration, adjusted for all covariates ($P < 0.0001$). Specifically, for every 10° increase in the change in facultative skin color ITA, indicating less tanning, serum 25(OH)D concentration was 1.5 ng/mL lower ($\beta = -0.15$, 95% CI = −0.23, −0.08). After adjusting for race/ethnicity (model 2),

TABLE 1 Study population characteristics by race/ethnicity[1]

	Total sample	White/Caucasian	Black/African American	Hispanic/Latino	Asian	Multiracial/other	*P* value
n	426	184	47	93	36	66	
Female, %	51.2	45.7	59.6	58.1	58.3	47.0	0.16
Age, y	11.7 ± 1.4	11.6 ± 1.4	11.7 ± 1.4	11.7 ± 1.3	11.9 ± 1.7	11.7 ± 1.5	0.81
BMI *z* score	0.92 (1.7)	0.84 (1.6)[a]	1.01 (1.4)[a]	1.11 (1.6)[a]	0.07 (2.1)[b]	0.90 (1.4)[a]	0.0028
Overweight/obese, %	45.1	44.0	46.8	54.8	27.8	42.4	0.08
Serum 25(OH)D, ng/mL							
Pre-summer	29.3 ± 9.5	29.9 ± 8.9	29.6 ± 12.8	27.6 ± 8.7	27.5 ± 7.7	30.7 ± 9.9	0.18
Post-summer	25.6 ± 7.9	27.8 ± 8.3[a]	22.4 ± 8.1[b]	23.8 ± 6.0[b]	22.8 ± 6.5[b]	25.9 ± 8.2[a,b]	<0.0001
Change over summer[2]	−3.7 ± 8.7	−2.1 ± 9.8[b]	−7.2 ± 5.7[a]	−3.9 ± 7.7[a,b]	−4.8 ± 5.7[a,b]	−4.8 ± 7.8[a,b]	<0.01
Dietary vitamin D intake,[3] IU/d	115 ± 62.5	120 ± 65.6	110 ± 60.4	106 ± 52.5	113 ± 68.2	115 ± 64.8	0.46
Vitamin D supplement use,[4] %	17.4	17.4	19.1	17.2	13.9	18.2	0.98
Constitutive skin color,[5] ITA	38.9 ± 23.8	53.7 ± 10.0[a]	−10.9 ± 21.0[e]	40.1 ± 9.7[b]	34.0 ± 12.9[b,c]	33.8 ± 20.9[d]	<0.0001
Facultative skin color, ITA							
Pre-summer	19.4 ± 23.5	32.9 ± 13.5[a]	−26.2 ± 18.8[c]	20.2 ± 12.5[b]	16.5 ± 15.9[b]	14.5 ± 20.9[b]	<0.0001
Post-summer	10.8 ± 22.9	24.7 ± 12.1[a]	−34.4 ± 15.9[d]	11.5 ± 13.3[b]	7.7 ± 15.9[b,c]	4.7 ± 19.9[c]	<0.0001
Change over summer (tanning)[2]	−8.6 ± 8.6	−8.2 ± 9.1	−8.2 ± 8.4	−8.7 ± 8.6	−8.8 ± 6.5	−9.8 ± 8.7	0.77
Sedentary time ≥4 h/d, %	13.6	7.1	23.4	16.1	36.1	9.1	<0.0001
Free or reduced-price lunch, %	66.4	47.3	89.4	82.8	75.0	75.8	<0.0001
Late puberty/post-pubertal,[4] %	48.6	40.8	48.9	52.7	52.8	62.1	0.04

[1] Values are means ± SDs or medians (IQRs) unless otherwise indicated. Labeled race/ethnicity values in a row without a common superscript letter are significantly different, $P < 0.05$. ITA, individual typology angle; 25(OH)D, 25-hydroxyvitamin D.
[2] Post-summer − pre-summer value.
[3] Means of pre- and post-summer measurements, adjusted for total energy intake.
[4] Post-summer.
[5] Pre-summer.

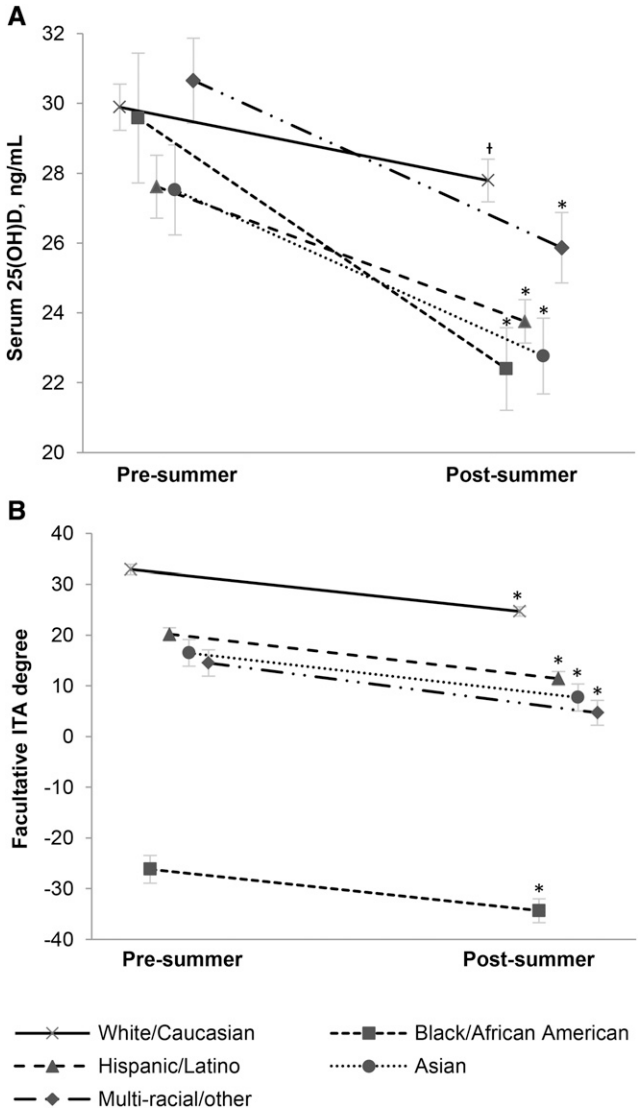

FIGURE 1 Serum 25-hydroxyvitamin D concentrations (A) and facultative skin color, reflecting tanning (B) pre-summer (April–June) and post-summer (September–December) in children of different racial/ethnic groups. Values are means ± SEs, n = 184 (white/Caucasian), 47 (black/African American), 93 (Hispanic/Latino), 36 (Asian), or 66 (multiracial/ethnic). *,†Different from pre-summer: *$P < 0.0001$; †$P < 0.01$. ITA, individual typology angle; 25(OH)D, 25-hydroxyvitamin D.

tanning remained highly significant ($P < 0.0001$). However, race/ethnicity was also a highly significant predictor of serum 25(OH)D concentration ($P < 0.001$). Compared with white/Caucasian children, post-summer serum 25(OH)D concentration was 4.6 ng/mL lower for black/African American children ($P < 0.0001$), 3.4 ng/mL lower for Asian children ($P < 0.01$), 2.5 ng/mL lower for Hispanic/Latino children ($P < 0.01$), and 2.1 ng/mL lower for multiracial/other children ($P = 0.03$). With additional adjustment for constitutive skin color (model 3), again, tanning remained a highly significant predictor of 25(OH)D concentration ($P < 0.0001$). Constitutive skin color was also a significant predictor of 25(OH)D concentration ($P < 0.01$). For every 10° increase in constitutive skin color ITA, reflecting a lighter skin color, serum 25(OH)D concentration was 0.7 ng/mL higher (β = 0.07, 95% CI = 0.03, 0.12). Notably, when constitutive skin color was included in the model, race/ethnicity did not retain significance.

Discussion

In the present study, we observed that 6 mo after the DDHS winter supplementation, serum 25(OH)D concentration fell in all children despite tanning during the summer. Children with a higher degree of tanning demonstrated higher concentrations of serum 25(OH)D post-summer, after adjusting for pre-summer concentrations. Notably, children of different racial/ethnic groups all tanned to a similar extent during the summer months, reflecting similar exposure to sunlight. Despite this similarity, disparities in vitamin D status remained, with white/Caucasian children faring better than black/African American, Hispanic/Latino, Asian, and multiracial/other children. Additionally, when constitutive skin color was considered along with race/ethnicity, it was a stronger predictor of 25(OH)D concentration.

Studies have shown that individuals with darker skin color tend to have lower concentrations of serum 25(OH)D (29, 30), and even when exposed to the same amount of UVB light, those with darker skin types reached lower 25(OH)D concentrations than did those with lighter skin types (31, 32). This may be partially due to differences in melanin content, as melanin will compete for UVB radiation (9), resulting in a higher threshold for UVB-induced cutaneous vitamin D production in darker skin (31, 33). The results from this and other studies support the conclusion that individuals of darker skin pigmentation may require a longer duration of sun exposure to achieve a similar extent of vitamin D synthesis than those with lighter skin (1, 16, 31, 34). Emerging evidence also suggests that vitamin D-binding protein concentrations may differ between racial/ethnic groups, impacting the bioavailability of 25(OH)D, and may further explain differences in serum 25(OH)D concentration (35). However, data are limited in this area, and little is known about how vitamin D-binding protein may respond to vitamin D supplementation (36). Future examination of these factors, which the present study did not address, is warranted.

In much of the literature, skin color is defined by racial/ethnic group, but as multiracial and multiethnic groups grow, race/ethnicity becomes more of a social construct than a marker of biological differences. A multiracial or multiethnic individual may identify with one racial/ethnic group over another based on social or cultural influences and not necessarily based on biology or heredity. Therefore, a quantitative measure of skin color may prove more useful when examining vitamin D status in these populations, especially as it relates to sun exposure. In the present study, when constitutive skin color and race/ethnicity were considered together, the results suggested that much of the variability in serum 25(OH)D concentration between racial/ethnic groups may be accounted for by skin color and that a quantitative measure of skin color may be a better predictor of serum 25(OH)D than race/ethnicity.

Other studies have found conflicting evidence on relations between 25(OH)D concentration and different measures of skin color and race/ethnicity. Our results align with those of Armas et al. (16), who reported that serum 25(OH)D concentration was associated with constitutive skin color in a 4-wk intervention study of UVB exposure in adults. However, Rockell et al. (15) reported that serum 25(OH)D concentration was associated with tanning, but not with constitutive skin color. It is possible that the conflicting findings are due to the limitations of a cross-sectional design or the low number of darker-skinned participants in their study population. Au et al. (17), who examined the current study population of children at the baseline of the DDHS, reported that constitutive skin color was predictive of serum 25(OH)D concentration, similar to

TABLE 2 Association of post-summer serum 25(OH)D concentration with change in facultative skin color (tanning) over the summer in children (n = 426)[1]

	Model 1		Model 2		Model 3	
	β (95% CI)	*P* value	β (95% CI)	*P* value	β (95% CI)	*P* value
Tanning[2]	−0.15 (−0.23, −0.08)	< 0.0001	−0.17 (−0.24, −0.09)	<0.0001	−0.15 (−0.22, −0.07)	<0.0001
Race/ethnicity[3]				<0.001		0.19
White/Caucasian			ref		ref	
Black/African American			−4.56 (−6.73, −2.39)	<0.0001	0 (−3.56, 3.57)	1.00
Hispanic/Latino			−2.52 (−4.22, −0.82)	<0.01	−1.65 (−3.42, 0.12)	0.07
Asian			−3.41 (−5.85, −0.97)	<0.01	−2.15 (−4.69, 0.39)	0.10
Multiracial/other			−2.12 (−4.00, −0.24)	0.03	−0.71 (−2.77, 1.34)	0.50
Constitutive skin color[4]					0.07 (0.03, 0.12)	<0.01
Model R^2	0.34		0.38		0.39	

[1] Model 1 was adjusted for age, sex, BMI *z* score, energy-adjusted dietary vitamin D, sedentary time, free or reduced-price lunch, pubertal status, use of vitamin D supplements, and pre-summer serum 25(OH)D concentration. Model 2 was adjusted for variables in Model 1 plus race/ethnicity. Model 3 was adjusted for all variables in Models 1 and 2 plus constitutive skin color. ref, reference group; 25(OH)D, 25-hydroxyvitamin D.
[2] Change in facultative skin color, post-summer − pre-summer.
[3] n = 184, 47, 93, 36, and 66 for white/Caucasian, black/African American, Hispanic/Latino, Asian, and multiracial/ethnic, respectively.
[4] Pre-summer measurements.

results presented here, but much of the association disappeared when race/ethnicity and constitutive skin color were considered together. Again, a limitation may have been the cross-sectional design, as well as the analysis not including facultative skin color. Additionally, both studies may have been subject to error in the measurement of constitutive skin color. We noted that there was a small change in constitutive skin color over the summer (data not shown), suggesting that the upper inner arm may still be exposed to some sunlight during the warmer season. For this reason, we only used the pre-summer measurements of constitutive skin color in our analyses, whereas the aforementioned studies used measurements from the summer or early fall, when tanning of that area would have been possible.

After 6 mo of supplementation over the winter, all children on average achieved adequate serum 25(OH)D concentration, defined by the Institute of Medicine as ≥20 ng/mL. During the summer, the majority of children (83%) did not continue to use supplements containing vitamin D. Increased exposure to UVB radiation during the summer would normally be expected to increase serum 25(OH)D concentration; however, we observed a significant drop in 25(OH)D concentrations after the summer months in response to the cessation of supplements. Regardless of supplementation use in the winter, most people may anticipate getting adequate vitamin D through sun exposure alone in the summer. However, results from this study suggest that, in a racially/ethnically diverse population of children in the northeastern US, summer sun exposure may be inadequate to maintain serum 25(OH)D concentrations achieved through supplementation, particularly in children with darker skin pigmentation.

Children may be getting less overall sun exposure because they are spending more time indoors watching TV, playing video games, or using the computer (37–39). In this study, 14% of children self-reported ≥4 h/d screen time. Year-long supplementation may be beneficial, especially in those with more skin pigmentation, but children could also be encouraged to spend more time outdoors (40). Sun exposure for 5–30 min twice a wk has been recommended for sufficient production of vitamin D (1). The exact duration of sun exposure needed will depend on the time of day, season, latitude, and skin pigmentation.

In making these recommendations, consideration must be given to the potential harmful effects of the sun, especially the increased risk of skin cancer. With greater public awareness of the risks associated with too much sun exposure there has been an increase in the promotion and use of sunscreen in both children and adults (41, 42). There is some concern that because sunscreen can reduce the synthesis of vitamin D by >90% (43), the increase in sunscreen use may negatively impact vitamin D synthesis. However, there is also evidence that this impact may be negligible because of improper or inadequate use of sunscreen (44, 45). Further research is required to determine how and when sunscreen should be applied to maximize cutaneous vitamin D synthesis while also preventing damage from sun exposure.

Limitations of this study include parent report of race/ethnicity and self-reported data on dietary intake, physical activity, pubertal status, and postintervention vitamin D supplement use, which could result in measurement error, most likely in the direction of slight attenuation of study findings. We did not have specific information on sunscreen use or time spent outdoors during the summer; however, quantitative measures of skin color have been associated with time spent outdoors (15, 46). Additionally, small sample sizes within individual racial/ethnic groups prevented exploration of possible interactions. Strengths of this study include the use of reliable and reproducible quantitative measures of skin color (17). To our knowledge, this is the first study to examine the longitudinal relation between quantitative measures of skin color and serum 25(OH)D concentration in a racially/ethnically diverse population of children.

In summary, tanning significantly contributed to serum 25(OH)D concentrations over the summer months in this population, independent of race/ethnicity, but it was not sufficient to maintain the serum 25(OH)D concentrations attained with supplementation during the winter. Race/ethnicity was an important determinant of serum 25(OH)D concentration, but much of the variation in serum 25(OH)D concentration between racial/ethnic groups may be explained by skin color, suggesting that a quantitative measure of skin color may be a better predictor of serum 25(OH)D concentration than self-reported race/ethnicity. Future research should examine the increasingly complex relations between different measures of skin color, race/ethnicity, sun exposure, and vitamin D status.

Acknowledgments

We thank the Daily D Health Study coinvestigators Virginia Chomitz, Christina Economos, Elizabeth Goodman, and Michael Holick. CMS, MIVR, and JMS designed and conducted the research; CMS performed the statistical analyses; CMS, MIVR, and JMS wrote the paper; LEA and CMG provided expertise and critical feedback on the analysis and manuscript; and JMS had primary responsibility for the final content. All authors read and approved the final manuscript.

References

1. Holick MF, Vitamin D. Deficiency. N Engl J Med 2007;357:266–81.
2. Gordon CM, DePeter KC, Feldman HA, Grace E, Emans SJ. Prevalence of vitamin D deficiency among healthy adolescents. Arch Pediatr Adolesc Med 2004;158:531–7.
3. Sullivan SS, Rosen CJ, Halteman WA, Chen TC, Holick MF. Adolescent girls in Maine are at risk for vitamin D insufficiency. J Am Diet Assoc 2005;105:971–4.
4. Sacheck J, Goodman E, Chui K, Chomitz V, Must A, Economos C. Vitamin D deficiency, adiposity, and cardiometabolic risk in urban schoolchildren. J Pediatr 2011;159:945–50.
5. Au LE, Economos CD, Goodman E, Must A, Chomitz VR, Sacheck JM. Vitamin D intake and serum vitamin D in ethnically diverse urban schoolchildren. Public Health Nutr 2012;15:2047–53.
6. Holick MF. High prevalence of vitamin D inadequacy and implications for health. Mayo Clin Proc 2006;81:353–73.
7. Glerup H, Mikkelsen K, Poulsen L, Hass E, Overbeck S, Thomsen J, Charles P, Eriksen EF. Commonly recommended daily intake of vitamin D is not sufficient if sunlight exposure is limited. J Intern Med 2000;247:260–8.
8. Bonilla C, Ness AR, Wills AK, Lawlor DA, Lewis SJ, Davey Smith G. Skin pigmentation, sun exposure and vitamin D levels in children of the Avon Longitudinal Study of Parents and Children. BMC Public Health 2014;14:597.
9. Matsuoka LY, Wortsman J, Haddad JG, Kolm P, Hollis BW. Racial pigmentation and the cutaneous synthesis of vitamin D. Arch Dermatol 1991;127:536–8.
10. Nessvi S, Johansson L, Jopson J, Stewart A, Reeder A, McKenzie R, Scragg RK. Association of 25-hydroxyvitamin D3 levels in adult New Zealanders with ethnicity, skin color and self-reported skin sensitivity to sun exposure. Photochem Photobiol 2011;87: 1173–8.
11. Rockell JEP, Skeaff CM, Williams SM, Green TJ. Serum 25-hydroxyvitamin D concentrations of New Zealanders aged 15 years and older. Osteoporos Int 2006;17:1382–9.
12. Rockell JE, Green TJ, Skeaff CM, Whiting SJ, Taylor RW, Williams SM, Parnell WR, Scragg R, Wilson N, Schaaf D, et al. Season and ethnicity are determinants of serum 25-hydroxyvitamin D concentrations in New Zealand children aged 5–14 y. J Nutr 2005;135:2602–8.
13. Nesby-O'Dell S, Scanlon KS, Cogswell ME, Gillespie C, Hollis BW, Looker AC, Allen C, Doughertly C, Gunter EW, Bowman BA. Hypovitaminosis D prevalence and determinants among African American and white women of reproductive age: Third National Health and Nutrition Examination Survey, 1988–1994. Am J Clin Nutr 2002;76:187–92.
14. Libon F, Cavalier E, Nikkels AF. Skin color is relevant to vitamin D synthesis. Dermatology 2013;227:250–4.
15. Rockell JEP, Skeaff CM, Williams SM, Green TJ. Association between quantitative measures of skin color and plasma 25-hydroxyvitamin D. Osteoporos Int 2008;19:1639–42.
16. Armas LAG, Dowell S, Akhter M, Duthuluru S, Huerter C, Hollis BW, Lund R, Heaney RP. Ultraviolet-B radiation increases serum 25-hydroxyvitamin D levels: The effect of UVB dose and skin color. J Am Acad Dermatol 2007;57:588–93.
17. Au LE, Harris SS, Dwyer JT, Jacques PF, Sacheck JM. Association of serum 25-hydroxyvitamin D with race/ethnicity and constitutive skin color in urban schoolchildren. J Pediatr Endocrinol Metab 2014;27:1095–100.
18. Tangpricha V, Turner A, Spina C, Decastro S, Chen TC, Holick MF. Tanning is associated with optimal vitamin D status (serum 25-hydroxyvitamin D concentration) and higher bone mineral density. Am J Clin Nutr 2004;80:1645–9.
19. Sacheck JM, Van Rompay MI, Olson EM, Chomitz VR, Goodman E, Gordon CM, Eliasziw M, Holick MF, Economos CD. Recruitment and retention of urban schoolchildren into a randomized double-blind vitamin D supplementation trial. Clin Trials 2015;12:45–53.
20. Nwosu BU, Maranda L. The effects of vitamin D supplementation on hepatic dysfunction, vitamin D status, and glycemic control in children and adolescents with vitamin D deficiency and either type1 or type 2 diabetes mellitus. PLoS One 2014;9:e99646.
21. CDC Table for Calculated Body Mass Index Values for Selected Heights and Weights for Ages 2 to 20 Years [Internet]. Atlanta (GA): CDC; c2000 [cited 2014 Dec 13]. Available from: http://www.cdc.gov/nccdphp/dnpa/healthyweight/assessing/bmi/00binaries/bmi-tables.pdf.
22. Carskadon MA, Acebo C. A self-administered rating scale for pubertal development. J Adolesc Health 1993;14:190–5.
23. Cullen KW, Watson K, Zakeri I. Relative reliability and validity of the Block Kids Questionnaire among youth aged 10 to 17 years. J Am Diet Assoc 2008;108:862–6.
24. Marshall TA, Eichenberger Gilmore JM, Broffitt B, Stumbo PJ, Levy SM. Relative validity of the Iowa Fluoride Study targeted nutrient semi-quantitative questionnaire and the block kids' food questionnaire for estimating beverage, calcium, and vitamin D intakes by children. J Am Diet Assoc 2008;108:465–72.
25. Rockett HR, Breitenbach M, Frazier AL, Witschi J, Wolf AM, Field AE, Colditz GA. Validation of a youth/adolescent food frequency questionnaire. Prev Med 1997;26:808–16.
26. Eckhardt L, Mayer JA, Creech L, Johnston MR, Lui KJ, Sallis JF, Elder JP. Assessing children's ultraviolet radiation exposure: The potential usefulness of a colorimeter. Am J Public Health 1996;86:1802–4.
27. Taylor S, Westerhof W, Im S, Lim J. Noninvasive techniques for the evaluation of skin color. J Am Acad Dermatol 2006;54:S282–90.
28. Holick MF, Siris ES, Binkley N, Beard MK, Khan A, Katzer JT, Petruschke RA, Chen E, de Papp AE. Prevalence of vitamin D inadequacy among postmenopausal North American women receiving osteoporosis therapy. J Clin Endocrinol Metab 2005;90:3215–24.
29. Looker AC, Johnson CL, Lacher DA, Pfeiffer CM, Schleicher RL, Sempos CT. Vitamin D status: United States, 2001–2006. NCHS Data Brief 2011; 1–8.
30. Harris SS, Dawson-Hughes B. Seasonal changes in plasma 25-hydroxyvitamin D concentrations of young American black and white women. Am J Clin Nutr 1998;67:1232–6.
31. Chen TC, Chimeh F, Lu Z, Mathieu J, Person KS, Zhang A, Kohn N, Martinello S, Berkowitz R, Holick MF. Factors that influence the cutaneous synthesis and dietary sources of vitamin D. Arch Biochem Biophys 2007;460:213–7.
32. Clemens TL, Adams JS, Henderson SL, Holick MF. Increased skin pigment reduces the capacity of skin to synthesise vitamin D3. Lancet 1982;1:74–6.
33. Freedman DM, Cahoon EK, Rajaraman P, Major JM, Doody MM, Alexander BH, Hoffbeck RW, Kimlin MG, Graubard BI, Linet MS. Sunlight and other determinants of circulating 25-hydroxyvitamin D levels in black and white participants in a nationwide U.S. study. Am J Epidemiol 2013;177:180–92.
34. Bogh MKB, Schmedes AV, Philipsen PA, Thieden E, Wulf HC. Vitamin D production after UVB exposure depends on baseline vitamin D and total cholesterol but not on skin pigmentation. J Invest Dermatol 2010;130:546–53.
35. Holick MF. Bioavailability of vitamin D and its metabolites in black and white adults. N Engl J Med 2013;369:2047–8.
36. Ponda MP, McGee D, Breslow JL. Vitamin D-binding protein levels do not influence the effect of vitamin D repletion on serum PTH and calcium: Data from a randomized, controlled trial. J Clin Endocrinol Metab 2014;99:2494–9.
37. Carson V, Rosu A, Janssen I. A cross-sectional study of the environment, physical activity, and screen time among young children and their parents. BMC Public Health 2014;14:61.

38. Wethington H, Pan L, Sherry B. The association of screen time, television in the bedroom, and obesity among school-aged youth: 2007 National Survey of Children's Health. J Sch Health 2013;83: 573–81.
39. Atkin AJ, Sharp SJ, Corder K, van Sluijs EMF; International Children's Accelerometry Database (ICAD) Collaborators. Prevalence and correlates of screen time in youth: An international perspective. Am J Prev Med 2014;47:803–7.
40. Baggerly CA, Cuomo RE, French CB, Garland CF, Gorham ED, Grant WB, Heaney RP, Holick MF, Hollis BW, McDonnell SL, et al. Sunlight and vitamin D: necessary for public health. J Am Coll Nutr 2015;34:359–65.
41. Tripp MK, Herrmann NB, Parcel GS, Chamberlain RM, Gritz ER. Sun Protection is Fun!: A skin cancer prevention program for preschools. J Sch Health 2000;70:395–401.
42. Robinson JK, Rigel DS, Amonette RA. Summertime sun protection used by adults for their children. J Am Acad Dermatol 2000;42: 746–53.
43. Matsuoka LY, Ide L, Wortsman J, MacLaughlin JA, Holick MF. Sunscreens suppress cutaneous vitamin D_3 synthesis. J Clin Endocrinol Metab 1987;64:1165–8.
44. Springbett P, Buglass S, Young AR. Photoprotection and vitamin D status. J Photochem Photobiol B 2010;101:160–8.
45. Diehl JW, Chiu MW. Effects of ambient sunlight and photoprotection on vitamin D status. Dermatol Ther 2010;23:48–60.
46. Malvy DJ, Guinot C, Preziosi P, Galan P, Chapuy MC, Maamer M, Arnaud S, Meunier PJ, Hercberg S, Tschachler E. Relationship between vitamin D status and skin phototype in general adult population. Photochem Photobiol 2000;71:466–9.