Sun-Exposed Skin Color Is Associated with Changes in Serum 25-Hydroxyvitamin D in Racially/Ethnically Diverse Children\textsuperscript{1,2}

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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 (β = −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]\textsuperscript{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
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 D3) (8–10). Vitamin D3 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 (11).

The amount of pre-vitamin D3 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 D3 synthesis (8). Therefore, individuals with higher amounts of melanin, conferring a darker skin color, would have reduced vitamin D3 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 (facilitative) 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 facilitative 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 = 683 at baseline) were supplemented with 1 of 3 possible vitamin D3 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 ascribed in one of the following categories: white/Caucasian, black/African American, Mexican/Mexican American, other Hispanic/Latino, Asian/Asian American/Asian Indian, Native 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 <300 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 (ITA = [(ArcTangent(L−500/b)) × 180/π], 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-MSMS on a TSQ Quantum Ultra triple mass spectrometer (Thermo Finnigan Corp.). This method included fractionation of 25-hydroxyergocalciferol [25(OH)D2], 25-hydroxycholecalciferol [25(OH)D3], and epimer of 25(OH)D3 in serum (28). 25(OH)D3 and 25(OH)D2 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)D3 and 25(OH)D2 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 = 0.016). 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 1A); 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 (β = −0.15, 95% CI = −0.23, −0.08). After adjusting for race/ethnicity (model 2),

### Table 1  Study population characteristics by race/ethnicity

<table>
<thead>
<tr>
<th></th>
<th>Total sample</th>
<th>White/Caucasian</th>
<th>Black/African American</th>
<th>Hispanic/Latino</th>
<th>Asian</th>
<th>Multiracial/other</th>
<th>P value</th>
</tr>
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<tbody>
<tr>
<td>n</td>
<td>426</td>
<td>184</td>
<td>47</td>
<td>93</td>
<td>38</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td>Female, %</td>
<td>51.2</td>
<td>45.7</td>
<td>59.6</td>
<td>56.1</td>
<td>58.3</td>
<td>47.0</td>
<td>0.16</td>
</tr>
<tr>
<td>Age, y</td>
<td>11.7 ± 1.4</td>
<td>11.6 ± 1.4</td>
<td>11.7 ± 1.4</td>
<td>11.7 ± 1.3</td>
<td>11.9 ± 1.7</td>
<td>11.7 ± 1.5</td>
<td>0.81</td>
</tr>
<tr>
<td>BMI z score</td>
<td>0.92 (1.7)</td>
<td>0.84 (1.6)b</td>
<td>1.01 (1.4)b</td>
<td>1.11 (1.6)b</td>
<td>0.07 (2.1)b</td>
<td>0.90 (1.4)b</td>
<td>0.0028</td>
</tr>
<tr>
<td>Overweight/obese, %</td>
<td>45.1</td>
<td>44.0</td>
<td>46.8</td>
<td>54.8</td>
<td>27.8</td>
<td>42.4</td>
<td>0.08</td>
</tr>
<tr>
<td>Serum 25(OH)D, ng/mL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-summer</td>
<td>29.3 ± 9.5</td>
<td>29.9 ± 8.9</td>
<td>27.6 ± 12.8</td>
<td>27.5 ± 7.7</td>
<td>30.7 ± 9.9</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>Post-summer</td>
<td>25.6 ± 7.9</td>
<td>27.8 ± 8.3a</td>
<td>22.4 ± 8.1b</td>
<td>23.8 ± 6.0a</td>
<td>22.8 ± 6.5b</td>
<td>25.9 ± 8.2ab</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Change over summer</td>
<td>−3.7 ± 8.7</td>
<td>−2.1 ± 9.8a</td>
<td>−7.2 ± 6.7a</td>
<td>−3.9 ± 7.7ab</td>
<td>−4.8 ± 5.7ab</td>
<td>−4.8 ± 7.8b</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Dietary vitamin D intake, IU/d</td>
<td>115 ± 62</td>
<td>120 ± 65.6</td>
<td>110 ± 60.4</td>
<td>106 ± 52.5</td>
<td>113 ± 68.2</td>
<td>115 ± 64.8</td>
<td>0.46</td>
</tr>
<tr>
<td>Vitamin D supplement use, %</td>
<td>17.4</td>
<td>17.4</td>
<td>19.1</td>
<td>17.2</td>
<td>13.9</td>
<td>18.2</td>
<td>0.98</td>
</tr>
<tr>
<td>Constitutive skin color, ITA</td>
<td>38.9 ± 23.8</td>
<td>53.7 ± 10.0a</td>
<td>−10.9 ± 21.0a</td>
<td>40.1 ± 9.7b</td>
<td>34.0 ± 12.9b</td>
<td>33.8 ± 20.9d</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Facultative skin color, ITA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-summer</td>
<td>19.4 ± 23.5</td>
<td>32.9 ± 13.5a</td>
<td>−26.2 ± 18.8a</td>
<td>20.2 ± 12.5b</td>
<td>16.5 ± 15.9b</td>
<td>14.5 ± 20.9b</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Post-summer</td>
<td>10.8 ± 22.9</td>
<td>24.7 ± 12.1a</td>
<td>−34.4 ± 15.9b</td>
<td>11.5 ± 13.3b</td>
<td>7.7 ± 15.9b</td>
<td>4.7 ± 19.9b</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Change over summer (tanning)</td>
<td>−8.6 ± 8.6</td>
<td>−8.2 ± 9.1</td>
<td>−8.2 ± 8.4</td>
<td>−8.7 ± 8.6</td>
<td>−8.8 ± 6.5</td>
<td>−9.8 ± 8.7</td>
<td>0.77</td>
</tr>
<tr>
<td>Sedentary time ≥4 h/d, %</td>
<td>13.6</td>
<td>7.1</td>
<td>23.4</td>
<td>16.1</td>
<td>36.1</td>
<td>9.1</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Free or reduced-price lunch, %</td>
<td>66.4</td>
<td>47.3</td>
<td>89.4</td>
<td>82.8</td>
<td>75.0</td>
<td>75.8</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Late puberty/post-pubertal, %</td>
<td>48.6</td>
<td>40.9</td>
<td>52.7</td>
<td>52.8</td>
<td>62.1</td>
<td>0.04</td>
<td></td>
</tr>
</tbody>
</table>

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.
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...
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 this population of children. 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 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.

## 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

<table>
<thead>
<tr>
<th></th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>β (95% CI)</td>
<td>P value</td>
<td>β (95% CI)</td>
</tr>
<tr>
<td>Tanning</td>
<td>−0.15 (−0.23, −0.08)</td>
<td>&lt; 0.0001</td>
<td>−0.17 (−0.24, −0.09)</td>
</tr>
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<td>Race/ethnicity</td>
<td>&lt; 0.001</td>
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<td></td>
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<tr>
<td>Black/African American</td>
<td>−4.56 (−6.73, −2.39)</td>
<td>&lt; 0.0001</td>
<td>0 (−3.56, 3.57)</td>
</tr>
<tr>
<td>Hispanic/Latino</td>
<td>−2.52 (−4.22, −0.82)</td>
<td>&lt; 0.01</td>
<td>−1.65 (−3.42, 0.12)</td>
</tr>
<tr>
<td>Asian</td>
<td>−3.41 (−5.85, −0.97)</td>
<td>&lt; 0.01</td>
<td>−2.15 (−4.68, 0.39)</td>
</tr>
<tr>
<td>Multiracial/other</td>
<td>−2.12 (−4.00, −0.24)</td>
<td>0.03</td>
<td>−0.71 (−2.77, 1.14)</td>
</tr>
<tr>
<td>Constitutive skin color2</td>
<td></td>
<td></td>
<td>0.07 (0.03, 0.12)</td>
</tr>
<tr>
<td>Model R²</td>
<td>0.34</td>
<td>0.38</td>
<td>0.39</td>
</tr>
</tbody>
</table>

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.
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References


