ARTICLE

Prevalence of Vitamin D Deficiency Among Healthy Adolescents

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Background: Although vitamin D deficiency has been documented as a frequent problem in studies of young adults, elderly persons, and children in other countries, there are limited data on the prevalence of this nutritional deficiency among healthy US teenagers.

Objective: To determine the prevalence of vitamin D deficiency in healthy adolescents presenting for primary care.

Design: A cross-sectional clinic-based sample.

Setting: An urban hospital in Boston.

Participants: Three hundred seven adolescents recruited at an annual physical examination to undergo a blood test and nutritional and activity assessments.

Main Outcome Measures: Serum levels of 25-hydroxyvitamin D (25OHD) and parathyroid hormone, anthropometric data, nutritional intake, and weekly physical activity and lifestyle variables that were potential risk factors for hypovitaminosis D.

Results: Seventy-four patients (24.1%) were vitamin D deficient (serum 25OHD level, ≤15 ng/mL [≤37.5 nmol/L]), of whom 14 (4.6%) were severely vitamin D deficient (25OHD level, ≤8 ng/mL [≤20 nmol/L]). By using a broader definition (25OHD level, ≤20 ng/mL [≤50 nmol/L]), 129 patients (42.0%) were vitamin D insufficient. Serum 25OHD levels were inversely correlated with parathyroid hormone levels (r=–0.29), and were 24% lower during winter compared with summer. In a final multivariate model, season, ethnicity, milk and juice consumption, body mass index, and physical activity were significant independent predictors of hypovitaminosis D.

Conclusions: Vitamin D deficiency was present in many US adolescents in this urban clinic-based sample. The prevalence was highest in African American teenagers and during winter, although the problem seems to be common across sex, season, and ethnicity.

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DURING CHILDHOOD AND adolescence, vitamin D is important for calcium absorption and bone growth and accretion. In addition to skeletal effects, including maintenance of normal bone turnover, mineralization during adulthood, and prevention of rickets in children, vitamin D may confer protection against health problems such as type 1 diabetes mellitus, hypertension, multiple sclerosis, and cancer.[1]

There are growing data from studies of young adults,[2] elderly persons,[3-5] and youth in other countries that vitamin D deficiency is an unrecognized and prevalent health problem.[6-10] Despite milk fortification in this country, subclinical vitamin D deficiency has been noted, with a high prevalence in adult medical inpatients,[11] homebound elderly individuals,[3] postmenopausal women presenting with hip fracture,[5] and healthy young adults.[2] Few data are available regarding the prevalence of this nutritional deficiency among healthy US children and adolescents. Building on data from the Third National Health and Nutrition Examination Survey, in which serum 25-hydroxyvitamin D (25OHD) levels were measured and vitamin D deficiency (25OHD level, ≤15 ng/mL [≤37.5 nmol/L]) was found in 17% of southern adolescents during winter and 8% of northern teenagers during summer,[12] we sought to examine the prevalence of hypovitaminosis D and secondary hyperparathyroidism in an adolescent cohort during each season, because parathyroid hormone (PTH) levels were not measured as part of the Third National Health and Nutrition Examination Survey. To our knowledge, no previous studies have examined the prevalence of this problem in adolescent boys and girls in the

United States across the 4 seasons. Adolescents in Boston are at increased risk for vitamin D deficiency because the high latitude precludes cutaneous vitamin synthesis during winter.[13] Thus, we undertook the present study in our adolescent medicine clinic to determine the prevalence of vitamin D deficiency among an urban convenience sample of otherwise healthy teenagers.

The primary objective of this study was to test the hypothesis that vitamin D deficiency (25OHD level, ≤15 ng/mL) is prevalent among healthy adolescents. The secondary objective was to determine whether a seasonal variation existed for serum 25OHD and PTH levels, testing the hypothesis that 25OHD levels would be lower and PTH levels higher during winter. Last, we sought to identify factors within the adolescent lifestyle that represent predictors of hypovitaminosis D.

METHODS

STUDY POPULATION

We studied 307 primary care patients (aged 11-18 years) who presented consecutively for annual physical examinations between July 1, 2001, and June 30, 2003, to the adolescent outpatient clinic at Children's Hospital Boston and were undergoing a routine blood draw (eg, complete blood cell count). Participants were classified according to season, with a special emphasis on patients enrolled between July and September and between January and March. Exclusion criteria included a chronic illness and use of medications known to affect bone metabolism; patients for whom blood tests were ordered for purposes outside of routine health screening were also excluded. Approximately 780 patients were identified as potentially eligible candidates for the present study. Patients excluded included those who were being seen for a sick visit, those who were not having blood drawn, and those who were undergoing blood tests beyond a routine blood cell count or lipid panel. Of the patients, 39.4% met the enrollment criteria, agreed to participate, and were enrolled. All participants provided written informed consent; for those younger than 18 years, a parent or guardian also provided consent. The Committee on Clinical Investigation, Children's Hospital Boston, approved the protocol.

DATA COLLECTION

Data were collected on patients from that day's visit, including age, sex, self-declared ethnicity, height, and weight. Participants completed an intake form, with questions related to medical history, exercise, and general diet (eg, milk consumption).

Participants completed detailed questionnaires regarding their typical nutritional intake and physical activity during the previous year, including an assessment of calcium and vitamin D intake (dietary and supplements) and participation in sports and other activities, as described previously.[14-17] The nutritional questionnaire, the Youth and Adolescent Questionnaire, was a food frequency inventory designed especially for older children and adolescents[16] that has been validated[17] and is reproducible.[16] The activity questionnaire asked participants to recall time spent on team sports and other activities.[14,18] Activity was then computed in terms of total hours per week and time engaged in outdoor activities.

LABORATORY MEASUREMENTS

One blood sample (15 mL) was obtained for each subject at the end of the health visit. All tests were performed in the hospital clinical laboratory using kits provided by the same manufacturer (Nichols Institute, San Clemente, Calif). Serum 25OHD levels were measured by competitive binding assay, and intact PTH levels by a 2-site chemiluminescence immunoassay (Nichols Institute). Serum calcium, phosphorus, and magnesium levels were measured by end point assay in a multichannel analyzer (Roche/Hitachi model; Roche, Branchburg, NJ). The samples were analyzed in multiple assays. Interassay coefficients of variation were 5.4% to 7.0% for PTH, 9.0% to 15.0% for 25OHD (15.0% for lower values; sensitivity of the assay, 5-9 ng/mL [12.5-22.5 nmol/L]), and 1.5% to 2.2% for the cations.

The patients were divided into 3 diagnostic categories according to their serum 25OHD concentrations, as rounded to the nearest integer. In increasing order of severity, the 25OHD levels were as follows: vitamin D insufficiency, 20 ng/mL or less (≤50 nmol/L); vitamin D deficiency, 15 ng/mL or less (≤37.5 nmol/L); and severe vitamin D deficiency, 8 ng/mL or less (≤20 nmol/L). The definition of vitamin D deficiency was based on data from previous studies[3,19-21] showing that patients with serum 25OHD levels of 15 ng/mL or less had elevated serum PTH concentrations. The definition of severe vitamin D deficiency was based on the assay threshold (9 ng/mL [22.5 nmol/L]) for 25OHD, according to the normal range of the Nichols Institute. The definition of vitamin D insufficiency has been used previously in adults[2,22] and children.[6,12]

STATISTICAL ANALYSIS

In designing the study, we specified that, in our clinic population, a 5% prevalence of vitamin D deficiency would be considered clinically significant. To rule out any lower prevalence, the sample of 300 provided 80% power using a 2-sided 95% confidence interval, provided the underlying prevalence was at least 9.8%. The ultimate prevalence estimate was 24.1%, with a lower 95% confidence limit of 19.5%, well above the prespecified threshold for clinical significance.

The serum 25OHD level showed a skewed distribution and was accordingly log transformed for analysis, to prevent undue influence of extreme values. Milk consumption of more than 1.44 L/d was rendered as 1.44 L/d, and self-reported physical activity was categorized as 0 to 2, 3 to 7, or more than 7 h/wk. Three activity estimates of more than 40 h/wk were excluded as outliers, per instructions of the instrument.[14]

To assess simple bivariate associations among serum 25OHD level, vitamin D deficiency, and predictor variables, we used the χ^2 statistic, the *t* test, linear regression, a 1-way analysis of variance, the Kruskal-Wallis test, and Pearson product moment or Spearman rank correlation, as appropriate to the nature and distribution of the variables.

We constructed a multiple regression model for 25OHD level using all predictors of interest, whether significant or not in simple regression. We identified confounding relationships by adding or removing a suspected confounder and observing the effect on statistical significance of the remaining variables in the model. From the final multiple regression model, we derived effect size estimates in the form of regression coefficients for the continuous predictors and scalar contrasts between levels or pertinent combinations of levels for the dichotomous (eg, sex) and polytomous (eg, season) predictors. The effects in log units (change in log 25OHD level) were converted to percentage units for reporting: 100%×[exp (change in log 25OHD level) – 1] (*exp* denotes exponential function). We constructed a corroborative logistic regression model using vitamin D deficiency (≤15 ng/mL) as the outcome variable and the same set of predictor variables. By using multiple logistic regression, an estimated prevalence of vitamin D deficiency was determined based on the ethnic distribution of US 15-year-old adolescents (66% white, 15% African American, 14%

Table 1. Clinical Characteristics of the 307 Participants

Characteristic	Value*
Age, y	
Mean ± SD	14.7 ± 2.0
Range	11-18
Sex	
Female	200 (65.1)
Male	107 (34.9)
Ethnicity	
White	49 (16.1)
African American	142 (46.7)
Hispanic	78 (25.7)
Asian	6 (2.0)
Other	29 (9.5)
Multivitamin use	37 (12.1)
Milk consumption, L/d	
Mean ± SD	0.46 ± 0.36
Range	0-1.92
Body mass index†	
Mean ± SD	23.8 ± 5.7
Range	15-39
Physical activity, h/wk	
Mean ± SD	5.8 ± 6.1
Range	0-40
Categories	
0-2	99 (32.6)
3-7	135 (44.4)
>7	70 (23.0)

*Data are given as number (percentage) unless otherwise indicated. Percentages are based on totals for each characteristic.

†Calculated as weight in kilograms divided by the square of height in meters.

Table 2. Prevalence of Vitamin D Deficiency in the Total Sample and in Subgroups

Variable	Total Subjects	No. (%) of Subjects With Vitamin D Deficiency*	OR (95% CI)†
All	307	74 (24.1)	NA
All, standardized	307	31 (10.1)‡	NA
Ethnicity			
African American	142	51 (35.9)	8.59 (2.53-29.20)
Hispanic	78	17 (21.8)	4.27 (1.18-15.50)
Asian	6	1 (16.7)	3.07 (0.26-35.70)
White	49	3 (6.1)	Reference
Sex			
Female	200	52 (26.0)	1.36 (0.77-2.39)
Male	107	22 (20.6)	Reference
Season			
Fall	89	15 (16.9)	1.47 (0.65-3.28)
Winter	66	26 (39.4)	4.70 (2.19-10.10)
Spring	45	20 (44.4)	5.78 (2.52-13.30)
Summer	107	13 (12.1)	Reference
Multivitamin use			
Yes	37	3 (8.1)	0.24 (0.07-0.82)
No	267	71 (26.6)	Reference
Body mass index	NA	NA	1.04 (0.99-1.09)

Abbreviations: CI, confidence interval; NA, data not applicable; OR, odds ratio.

*Defined as a 25-hydroxyvitamin D level of 15 ng/mL or less (≤37.5 nmol/L).

†From simple (unadjusted) logistic regression.

‡Projected to a hypothetical sample composed of equal numbers of male and female subjects, an equal distribution across 4 seasons, and the ethnic distribution of US 15-year-old adolescents.

Hispanic, 4% Asian, and 1% other), equal fractions by sex and season, and sample characteristics for exercise level, body mass index (calculated as weight in kilograms divided by the square of height in meters), and milk consumption.

Statistical analyses were conducted with a commercially available software program (SPSS for Windows; SPSS Inc, Chicago, Ill) and SAS statistical software (SAS Institute Inc, Cary, NC).

RESULTS

The final sample was composed of 307 subjects (**Table 1**). Serum calcium, phosphorus, and magnesium levels were normal.

PREVALENCE OF HYPOVITAMINOSIS D

The prevalence of vitamin D deficiency (serum 25OHD level, ≤15 ng/mL) in the total sample was 24.1%; the prevalence within subgroups is listed in **Table 2**, with the highest prevalence in African American adolescents compared with other ethnic groups. By using multiple logistic regression based on ethnic-specific rates extrapolated to the US population, the estimated prevalence of this deficiency was 10% (95% confidence interval, 5%-21%). Severe vitamin D deficiency (25OHD level, ≤8 ng/mL) was seen in 14 patients (4.6%), and vitamin D insufficiency (25OHD level, ≤20 ng/mL) was seen in 129 patients (42.0%). Hypovitaminosis D was also most prevalent during winter and spring compared with summer and fall (**Figure 1**). There was no significant difference

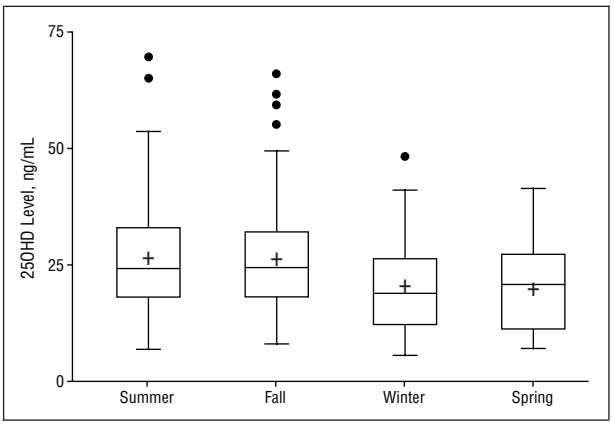

Figure 1. Box plot of seasonal variation in serum 25-hydroxyvitamin D (25OHD) level. The mean winter 25OHD level was significantly lower than that during summer, and concentrations between summer and fall and between winter and spring were similar. To convert 25OHD to nanomoles per liter, multiply by 2.496. The center line in the box indicates the median; +, the mean; the top and bottom of the box, quartile boundaries; vertical bars, minimum and maximum values within 1.5 times the interquartile range of the quartile boundary; and circles, more extreme values.

in prevalence between adolescent girls and boys (26.0% vs 20.6%, $P=.33$). There were significant relationships between consumption of selected food items and vitamin D deficiency (**Table 3**). There was a positive correlation between vitamin D deficiency and consumption of soft drinks, fruit juice, and iced tea, and an inverse correlation between the deficiency and consumption of milk and cold cereal (commonly fortified with vitamin

Table 3. Consumption of Selected Foods, With Relation to Vitamin D Deficiency, Reported by 294 Boston, Mass, Area Adolescents on the Youth and Adolescent Questionnaire

Food	Servings per Day, Median (25th-75th Percentile)	Vitamin D Deficiency, OR (95% CI)*
Soft drinks	0.57 (0.08-1.00)	1.56 (1.07-2.28)
Fruit juice	1.08 (0.22-2.00)	1.18 (0.93-1.49)
Iced tea	0 (0.00-0.36)	3.42 (1.34-8.72)
Milk and chocolate milk	0.71 (0.28-2.50)	0.75 (0.61-0.93)
Cold cereal	0.57 (0.08-1.00)	0.31 (0.16-0.59)
Yogurt	0.08 (0.00-0.14)	0.58 (0.25-1.37)
Cheese	0.57 (0.08-0.57)	1.10 (0.73-1.66)
Ice cream	0.14 (0.08-0.43)	0.81 (0.22-3.04)

Abbreviations: See Table 2.
*Defined as a 25-hydroxyvitamin D level of 15 ng/mL or less (≤37.5 nmol/L) and calculated per serving per day.

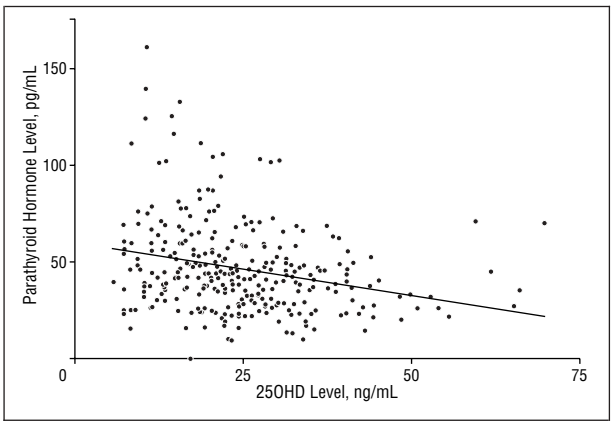

Figure 2. Relationship between serum 25-hydroxyvitamin D (25OHD) and parathyroid hormone levels. A significant (r=–0.29, P<.001) inverse correlation existed between these 2 variables. To convert 25OHD to nanomoles per liter, multiply by 2.496.

D). There was no significant correlation between vitamin D deficiency and consumption of yogurt, cheese, or ice cream (Table 3).

VARIABLES ASSOCIATED WITH 25OHD LEVELS

During summer, the mean±SD serum 25OHD level was significantly (P<.001) higher (26.2±11.2 ng/mL [65.5±28.0 nmol/L]) compared with during winter (20.2±9.9 ng/mL [50.3±24.7 nmol/L]). The mean±SD serum PTH level was 40.8±19.9 pg/mL during summer and significantly (P=.01) higher (50.3±25.6 pg/mL during winter. For the sample, there was a modest, but significant, inverse correlation between serum PTH and 25OHD levels (**Figure 2**).

Among the hypothesized predictors of 25OHD levels, we found several significant (P<.05) simple associations (data not shown). The 25OHD level was significantly higher in multivitamin users (P=.01), increased with milk (P=.002) and cold cereal consumption (P<.001), and was higher during summer (P<.001). The level decreased with juice (P=.03) and soft drink (P=.06) consumption and a higher body mass index (P=.006); it was lowest in the African American adolescents (P<.001).

Sex and activity showed a weak nonsignificant relation to 25OHD concentration in bivariate analyses. Both were retained for further examination in multiple regression analysis because of suspected confounding relationships to milk consumption and season, respectively. Outdoor and total activity levels showed no relation to 25OHD level, and were not considered further.

RELATIONSHIPS AMONG PREDICTORS

To provide a basis for interpretation of potential confounding relationships in multiple regression results, we examined the associations among predictor variables.

Use of multivitamins varied significantly by ethnic group (P=.004), with white patients reporting the highest multivitamin consumption (22.4%), compared with African American (8.5%), Hispanic (10.3%), and "other" (10.3%) patients. Among adolescent boys and girls, there was a modest, but significant, correlation between dietary vitamin D intake and 25OHD levels (adolescent girls, r=0.21, P=.004; and adolescent boys, r=0.25, P=.01). Daily milk consumption was significantly higher in adolescent boys (P<.001) (median, 0.48 L/d; range, 0-1.92 L/d) than in adolescent girls (median, 0.36 L/d; range, 0-1.68 L/d). There was no significant (P=.58) variation in milk consumption by ethnicity.

Physical activity varied significantly by sex (P=.01), with adolescent boys exercising a median of 5 h/wk (range, 0-40 h/wk) and adolescent girls exercising a median of 4 h/wk (range, 0-40 h/wk). Among ethnic groups, the variation in activity was only marginally significant (P=.04) by Kruskal-Wallis test and insignificant (P=.40) by χ^2 analysis. A high level of activity (>7 h/wk) was more common in fall, winter, and spring (26.9% of the sample) than in summer (15.9% of the sample) (**Table 4**).

There were no significant (P=.20) sex differences for mean±SD body mass index (adolescent girls vs adolescent boys, 24.2±5.9 vs 23.2±9.1).

INDEPENDENT PREDICTORS OF HYPOVITAMINOSIS D

In our final multiple regression model, ethnicity (P<.001), season (P<.001), body mass index (P=.003), milk (P=.003) and juice consumption (P=.02), and physical activity (P=.008) were significantly associated with 25OHD levels (Table 4). We found a significant interaction between milk consumption and season, with the effect of milk consumption being significant during winter and spring but not during summer and fall. An examination of alternative models confirmed that the gain in significance for activity was attributable to adjustment for season, which removed the confounding due to lower activity levels in summer. Multivitamin use remained weakly correlated with 25OHD level in a multiple regression analysis (P=.08), but lost statistical significance because of confounding with ethnicity (Table 4). In logistic regression models, the same independent predictors were identified, except that activity was not a significant (P=.96) correlate.

COMMENT

We found a high prevalence of vitamin D deficiency among otherwise healthy adolescents in a convenience sample from an urban adolescent clinic. These findings add to growing data, including findings from the Third National Health and Nutrition Examination Survey and cohorts of adolescent girls in Bangor, Maine, and Cleveland, Ohio,[12,23,24] suggesting that this nutritional deficiency is a prevalent problem among the pediatric age group, as has been previously documented in adults. To our knowledge, this is the first study to examine the prevalence of this problem in adolescent boys and girls throughout the year, in particular adolescents in the northeastern United States during the winter when the high latitude of Boston may preclude cutaneous synthesis of vitamin D. These data are similar to findings from 4 previous studies[2,5,11,22] of young and elderly Boston adults. Thus, these findings suggest that vitamin D deficiency is a problem spanning the age spectrum, particularly among African American adolescents and residents of a northern latitude.

Dietary and seasonal issues may explain the high prevalence of this nutritional deficiency among our otherwise healthy teenagers. Low levels of UV light exposure occur during winter in Boston,[20] likely explaining the seasonal variation observed. On this basis, 2 groups[25,26] have suggested that children in extreme northern or southern latitudes receive supplementation. Dietary factors may have also contributed. Milk consumption, an independent predictor of 25OHD levels, has decreased over recent years in children and adolescents, and with it, the adequate intake of calcium and vitamin D.[27] The decline seems to be due in part to increased soft drink and juice consumption.[27] Our data showing an inverse correlation between consumption of juices and soft drinks and serum 25OHD levels support this observation. A recent study[28] found that US women with low milk intake during childhood had a lower bone mass during adulthood and a higher risk of fracture, suggesting skeletal implications of this trend. The recent availability of vitamin D–fortified juices may help to alleviate this problem. We also found that use of multivitamins, preparations routinely containing vitamin D, was strikingly low in our clinic sample, and was lowest among African American patients.

The present study provides additional evidence that 25OHD levels should be maintained at more than 15 ng/mL to maintain normal skeletal dynamics. Although bone turnover markers were not measured in this study, hypovitaminosis D was accompanied by secondary hyperparathyroidism, potentially leading to increased bone resorption, the physiological significance of which is unknown in adolescents. An inverse relationship between PTH and 25OHD levels below 15 to 20 ng/mL has been reported in patients of different age groups. In addition to the present findings in these adolescents, this relationship exists in elderly persons,[19,20,29] healthy adults,[2] adult inpatients,[11] female outpatients,[21] children in Lebanon,[6] and adolescent boys in France.[8,9] In a study[30] of postmenopausal women, bone density was lower in those whose serum 25OHD levels were below 15 ng/mL.

We found that African American adolescents were more likely to have hypovitaminosis D than teenagers of other ethnic groups. The effects of sunlight exposure on vitamin D synthesis are decreased in individuals with darker skin pigmentation and in sunscreen users.[31] Studies[22,32,33] in adults have also shown that individuals with increased skin pigmentation have decreased vitamin D levels, including older African American adults,[32] Polynesian New Zealand residents,[33] and elderly low-income men and women in Boston.[22] Data from children and adolescents are more limited. Looker et al[12] found vitamin D deficiency most frequently in US non-Hispanic African American subjects, especially during winter in their study sites within the southern United States. Data for the Third National Health and Nutrition Examination Survey were collected during winter in the southern United States and during summer in the northern United States, preventing estimation of the prevalence of vitamin D deficiency in individuals living in the northeastern United States during winter, as was afforded by the present study. We also measured serum levels of PTH, another important calciotropic hormone, in addition to levels of 25OHD. Similarly, another study[34] showed the highest rate of hypovitaminosis D among African American women of reproductive age, complementing reports[35] of a high prevalence of nutritional rickets in African American breastfed infants. These findings confirm that more information is needed regarding appropriate screening practices and indications for supplementation for adolescents across ethnic groups. Because African American youth have been shown to have a higher bone density compared with other groups,[36] the long-term skeletal and other consequences of these findings deserve further study.

Table 4. Demographic, Environmental, Nutritional, and Behavioral Correlates of Serum Vitamin D Level in Boston, Mass, Area Adolescents, as Identified by Multiple Regression Analysis

Variable	Percentage Difference in Vitamin D Level (95% CI)*
Male vs female adolescents	1.6 (–8.3 to 12.7)
Ethnicity	
African American vs white adolescents	–40.0 (–47.7 to –31.3)
Hispanic vs white adolescents	–21.7 (–32.5 to –9.1)
Winter/spring vs summer/fall	–46.1 (–54.1 to –36.7)
Body mass index	–1.4 (–2.2 to –0.5)
Milk consumption†	
Winter/spring	13.0 (6.8 to 19.6)
Summer/fall	1.2 (–3.0 to 5.7)
Overall‡	7.0 (3.1 to 10.9)
Fruit juice consumption	–5.1 (–9.0 to –1.0)
Multivitamin use	12.6 (–2.4 to 29.8)
Exercise, h/wk	
3-7 vs 0-2	5.5 (–5.0 to 17.2)
>7 vs 0-2	21.7 (7.3 to 37.9)

Abbreviation: See Table 2.

*From multiple linear regression analysis of log-transformed 25-hydroxyvitamin D levels, adjusted for all list variables. Regression coefficients and limits of the 95% confidence interval [$b \pm (1.96 \times SE)$] were converted to percentage difference as follows: $100\% \times \{\exp [b \pm (1.96 \times SE)-1]\}$, where b signifies regression coefficient; SE, standard error; and exp, exponential function.

†Truncated as 1.44 L/wk.

‡Projected to a hypothetical sample equally distributed over 4 seasons, using the variables of the fitted regression model.

What This Study Adds

From previous research, vitamin D deficiency has been documented to be a common problem in adults and elderly persons, and in youth in other countries. We sought to determine the prevalence of vitamin D deficiency in US adolescents by studying otherwise healthy teenaged girls and boys who presented to our urban clinic in Boston. We found a high prevalence of vitamin D deficiency, 24.1% to 42.0% depending on the criteria used, in these healthy patients who presented for primary care. The problem was most frequent in African Americans and during winter, but was common in adolescent boys and girls and across ethnicity.

As shown in recent studies[37,38] of adults, we found an inverse correlation between body mass index and serum 25OHD concentration. Even after controlling for ethnicity, sex, and consumption of milk and juice, the body mass index remained an independent predictor of hypovitaminosis D in our final multivariate model. A study[39] of adults showed that obesity-associated vitamin D insufficiency is likely due to the decreased vitamin D bioavailability from cutaneous and dietary sources because of its deposition in body fat. In light of findings from adult studies and the increase of obesity among youth, the present data suggest a need to consider body mass index in the formulation of pediatric recommendations in this area.

These findings must be interpreted in light of acknowledged limitations. First, the study was cross-sectional and, therefore, causality cannot be inferred. Only a longitudinal study will be able to confirm that the identified correlates are definite risk factors for hypovitaminosis D and to determine whether vitamin D supplementation has significant beneficial health effects in adolescents. Second, the present study sample was enriched in subgroups known to be at higher risk for low vitamin D levels, including African American, Hispanic, and overweight teenagers; this may limit the generalizability of these findings. Nevertheless, even in our subgroup of white adolescents whose risk for vitamin D deficiency is lower, the prevalence of this problem still exceeded our predetermined level of concern. The present study group may also not be representative of Boston adolescents because of other unidentified causes of referral bias. We did not use a validated tool to measure sun exposure, an important predictor of serum 25OHD level. Although we obtained information on weekly outdoor activities, this measure provided only indirect information regarding sun exposure in these individuals, and no association was found between this variable and 25OHD concentration. In addition, we did not obtain information regarding sunscreen use, another potential confounder influencing cutaneous vitamin D synthesis. There was a significant inverse correlation between serum PTH and 25OHD levels for the sample. However, there were patients in whom the 25OHD concentration was subnormal, but the finding was not accompanied by secondary hyperparathyroidism, the clinical significance of which is unknown in young patients and deserves further study. Last, information on nutrition and activity was obtained by self-report in adolescents, with its inherent limitations.

In conclusion, we found a high prevalence of vitamin D deficiency in a sample of otherwise healthy US teenagers seen for primary care in an urban northeastern outpatient clinic. Even after adjusting for the ethnic distribution of teenagers in the United States, our estimated prevalence was still twice what we predetermined would be clinically significant. The association between hypovitaminosis D and dietary vitamin D and milk consumption suggests that attention should be paid to optimizing an adolescent's vitamin D intake, either by diet or supplementation. Having a higher body mass index and being of African American descent were associated with an increased risk of this nutritional deficiency in adolescents. The prevalence was highest during winter in our Boston clinic. Because vitamin D is critically important for the skeleton among other bodily tissues and functions, screening indications and guidelines for supplementation of children and adolescents should be evaluated, taking into account geography and identified risk factors. Longitudinal studies that provide data on health outcomes after supplementation also need to be carried out in children and adolescents.

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