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Prevalence of Vitamin D Deficiency Among Overweight and Obese US Children

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Prevalence of Vitamin D Deficiency Among Overweight and Obese US Children

WHAT'S KNOWN ON THIS SUBJECT: Adequate vitamin D is essential for skeletal health in developing children. Although excess body weight is associated with risk of vitamin D deficiency, the national prevalence of vitamin D deficiency in overweight and obese children is unknown.

WHAT THIS STUDY ADDS: Vitamin D deficiency is highly prevalent in overweight and obese children, and severely obese and minority children are disproportionately affected. There are many modifiable factors associated with vitamin D deficiency in overweight and obese children.

abstract

OBJECTIVE: Adequate vitamin D is essential for skeletal health in developing children. Although excess body weight is associated with risk of vitamin D deficiency, the national prevalence of and risk factors associated with vitamin D deficiency in overweight and obese children are unknown.

METHODS: The prevalence of vitamin D deficiency (defined as 25-hydroxyvitamin-D <20 ng/mL) was determined in a sample of 6- to 18-year-old children who were enrolled in a cross-sectional study (the 2003–2006 National Health and Nutrition Examination Survey) in which body weight and height were measured directly. Children were classified as healthy-weight, overweight, obese, or severely obese by using recommended age- and gender-specificBMI-percentile cut points. Associations between BMI-percentile classification and vitamin D deficiency were examined after adjustment for relevant confounders. Sample weights were used to generate nationally representative estimates.

RESULTS: The prevalence of vitamin D deficiency in healthy-weight, overweight, obese, and severely obese children was 21% (20%–22%), 29% (27%–31%), 34% (32%–36%), and 49% (45%–53%), respectively. The prevalence of vitamin D deficiency in severely obese white, Latino, and African-American children was 27% (3%–51%), 52% (36%–68%), and 87% (81%–93%), respectively. Compared with healthy-weight children, overweight, obese, and severely obese children had significantly greater adjusted odds of vitamin D deficiency. Modifiable factors associated with vitamin D deficiency in overweight/obese children were identified.

CONCLUSIONS: Vitamin D deficiency is highly prevalent in overweight and obese children. The particularly high prevalence in severely obese and minority children suggests that targeted screening and treatment guidance is needed. *Pediatrics* 2013;131:e152–e161

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KEY WORDS

vitamin D, obesity, disparities, screening, prevalence

ABBREVIATIONS

CDC—Centers for Disease Control and Prevention

NHANES—National Health and Nutrition Examination Survey

Dr Turer conceived of and designed the study, in addition to interpreting the data and drafting the article; Dr Lin acquired the data, conducted the data analyses, and aided in the interpretation of the data analysis; and Dr Flores supervised the conception and design of the study, aided in data interpretation, and critically revised the article.

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Vitamin D deficiency is associated with a host of chronic conditions, including hypertension, type 1 diabetes, and multiple sclerosis.[1] Established health consequences of vitamin D deficiency include increased fracture risk, tooth loss, osteomalacia, and rickets.[2] Because adequate vitamin D is essential for skeletal health,[1] and peak bone-mass accrual occurs during childhood and adolescence, identifying and treating vitamin D deficiency during this period may be particularly important.

Obesity has been suggested to be a risk factor for vitamin D deficiency.[1–3] The inverse association between higher body fat and lower vitamin D levels has been attributed to sequestration of the fat-soluble vitamin within the plentiful adipose tissue.[3] Other evidence suggests that excess body fat may disrupt hormonal pathways important for skeletal health.[4] For example, leptin, an adipocyte-derived hormone that binds to osteoblasts, appears to activate a pathway that inhibits renal synthesis of the active form of vitamin D.[4] Low dietary vitamin D intake and insufficient activity (resulting in limited sun exposure) also have been cited as possible confounding factors.[5,6]

INational population-based data, however, are lacking on the prevalence of and risk factors for vitamin D deficiency among overweight and obese children. Identifying vitamin D deficiency in these children may be particularly important for their skeletal and cardiovascular health. Fractures, Blount disease, and slipped capital femoral epiphysis are more common in obese children, and research suggests that vitamin D deficiency increases the risk of these conditions.[7–10] Cardiovascular disease risk factors and impaired glucose homeostasis also are associated with vitamin D deficiency and are more common in overweight and obese children.[11–13] Vitamin D deficiency also responds to supplementation.[14] Thus, national estimates of the prevalence of vitamin D deficiency among children classified into clinically useful BMI-percentile categories (overweight, obese, and severely obese) may inform the need for screening and treatment of vitamin D deficiency by primary care physicians.

The study objective was to determine the prevalence of and specific risk factors for vitamin D deficiency among overweight, obese, and severely obese children by using the most recent data available on vitamin D from a nationally representative sample of US children.

METHODS

Publicly available data from the 2003–2006 National Health and Nutrition Examination Surveys (NHANESs) were used for all analyses.[15] The NHANES is a stratified, multistage, probability sample survey conducted annually by the National Center for Health Statistics. Estimates, based on sampling weights, generalize to the entire noninstitutionalized, civilian US population. Written informed consent was obtained from parents for participants $<$18 years old, and from participants $\geq$12 years old. Written assent was obtained from children 7 to 11 years old. Participant characteristics are provided in Appendix 1.

Vitamin D deficiency was defined by using the Institute of Medicine definition of a serum 25-hydroxyvitamin-D $<$20 ng/mL ($<$50 nmol/L).[16] A 25-hydroxyvitamin-D level $\geq$20 ng/mL is associated with the absence of vitamin D deficiency rickets and osteomalacia for 98% of the population across all age groups.[17] Given that the optimal 25-hydroxyvitamin-D level to define vitamin D deficiency may differ for nonskeletal outcomes,[18] estimates of the prevalence of vitamin D insufficiency (25-hydroxyvitamin-D level $<$30 ng/mL) and severe deficiency ($<$12 ng/mL), and mean serum 25-hydroxyvitamin-D levels, also were determined, and are provided in Appendix 2.

In the NHANES, serum 25-hydroxyvitamin-D measurement was performed on venous blood samples collected in mobile examination centers by using standardized protocols. Measurements were performed by using the DiaSorin radioimmunoassay kit (Stillwater, MN) at the National Center for Environmental Health, Centers for Disease Control and Prevention (CDC; Atlanta, GA). The intra- and interassay coefficients of variation were 6.8% to 12.9% and 7.4% to 14.5%, respectively.[19] Adjusted 25-hydroxyvitamin-D data files, available since November 2010, were used for the current study, because quality control studies conducted by the CDC estimated that mean serum 25-hydroxyvitamin-D values in the NHANES 2003–2004 were overestimated, and in 2005–2006, were underestimated by 10% to 12%, due to assay reformulation and lot-to-lot variation in calibration.[20] Detailed information regarding adjusted data are available elsewhere.[20] The 2003–2006 NHANES serum 25-hydroxyvitamin-D levels are the most current data available; 25-hydroxyvitamin-D data have not yet been released for more recent NHANES waves.

Healthy-weight, overweight, obesity, and severe obesity were defined, respectively, as $\geq$5th to $<$85th, $\geq$85th to $<$95th, $\geq$95th to $<$99th, and $\geq$99th percentile of BMI for age and gender. BMI-percentile categories were defined by using cut points recommended by the CDC. Although no perfect cut point exists to determine all children with excess adiposity, these BMI-percentile categories are used by clinicians and researchers to assess risk for obesity-related disease in children.[21,22] Participant weight and height were measured directly during physical examinations in mobile examination centers by using standardized protocols and calibrated instruments. BMI was calculated as weight in kilograms divided by height in meters squared. BMI percentiles were determined by using age- and gender-specific CDC growth charts.[21]

Data for 6- to 18-year-old children from the NHANES 2003–2004 and 2005–2006 were merged. Those with valid data for 25-hydroxyvitamin-D and BMI were included (N = 12 711). Respondents classified as underweight (<5th percentile of BMI for age and gender) were excluded (N = 419).

Adjustment variables and risk factors were selected based upon previously reported associations with vitamin D levels to examine whether an independent association existed between BMI-percentile category and vitamin D deficiency (for example, after adjusting for diet and activity),[23–26] and to identify specific risk factors for vitamin D deficiency within each BMI-percentile category. Sociodemographic, dietary, and activity data were collected by parental report during in-person interviews. Sociodemographic characteristics included age (6–11 years versus 12–18 years old),[24] gender,[25] race/ethnicity,[26] and annual combined family income relative to the poverty threshold in the years of the survey.[27] Child race/ethnicity was self-reported by parents; in keeping with the increasingly accepted convention to provide mutually exclusive racial/ethnic categories (rather than arbitrarily assigning race to Latinos/Hispanics), race/ethnicity was categorized in this study as non-Latino white (referred to as white), non-Latino African-American/black (referred to as African-American), and Latino/Hispanic (referred to as Latino). All other race/ethnicities (American Indian/Alaskan Native, Asian-Pacific Islander, and multiracial) were classified as "other," due to insufficient sample sizes for each group. Season of serum collection was recorded in the NHANES as summer/autumn versus winter/spring and indirectly reflects geographic region of serum collection (to avoid weather damage to the mobile examination centers, data are collected May through October in the northern United States and November through April in the southern United States). Detailed geographic data were not accessible in the publicly available data set.

Supplemental sources of vitamin D from dietary supplements and milk were examined. Milk comprises approximately half of all dietary sources of vitamin D, and of the top 20 dietary sources of vitamin D consumed by US children, 7 are milk products (including, skim, 1%, 2%, whole, chocolate 1%, chocolate 2%, and unknown % fat milk). Other dietary sources of vitamin D were not analyzed, because each provides less than one-tenth of dietary vitamin D intake.[28] Use of dietary supplements containing vitamin D was determined by using responses from the dietary-supplement and prescription-medication questionnaires. Missing data precluded examination of the dosage of vitamin D. Milk intake was assessed by food frequency questionnaire in the NHANES; daily milk intake was determined by using the variable, "number of milk-cup equivalents."

Physical and sedentary activity might influence vitamin D levels by promoting or limiting time spent outdoors and sun exposure.[6] Information on physical activity was obtained during the NHANES household interviews for respondents 6 to 11 years old and ≥16 years old. Twelve- to 15-year-old respondents provided activity data during physical examinations. Duration of physical activity per week was determined from the mean number of hours that respondents reported playing or exercising enough to sweat or breathe hard. Answers were categorized into tertiles as none to <2, ≥2 to <5, and ≥5 hours per week. Information on TV and computer use was obtained during household interviews. Responses to 2 questions (hours per day watching TV/videos and using a computer) were summed to yield the mean total hours of TV/computer use per day, and categorized into none to ≤2, >2 to ≤4, and >4 hours per day. Analysis of the activity variables as continuous variables did not alter the study results. Collinearity was tested by using a variance inflation factor; no collinear relationships were detected.

Bivariate analyses were performed by using Pearson's χ^2 statistic to compare the prevalence of vitamin D deficiency among BMI-percentile categories and to identify factors associated with vitamin D deficiency for each BMI-percentile category. A $P < .05$ was considered to be statistically significant.

Multiple logistic regression was used to examine the independent association between BMI-percentile category and vitamin D deficiency, after adjustment for confounders, and to identify factors associated with vitamin D deficiency for children within each BMI-percentile category; due to the smaller number of severely obese children, however, factors associated with vitamin D also were identified for obese/severely obese children combined. Stepwise model selection was used to evaluate the independent association between BMI-percentile category and vitamin D deficiency, after adjusting for baseline characteristics alone (race/ethnicity, age, gender, poverty, and season of serum collection), with activity (TV/computer use and physical activity), with vitamin D supplementation and milk intake, and with all independent variables forced into the model. To identify factors associated with vitamin D deficiency for children within each BMI-percentile category, all statistically significant independent variables were forced into the models.

Statistical analyses were conducted by using SAS version 9.2 (SAS Institute, Inc, Cary, NC). To adjust for the complex probability survey design of the NHANES, sampling weights, stratification, and clustering were incorporated into analyses to provide national estimates and standard errors. Sampling errors were estimated by the Taylor series (linearization) method using SAS survey procedure. Sampling weights were used to account for unequal probabilities of selection, nonresponse, and adjustments for independent population controls.

RESULTS

Of 12 292 children in the sample, equivalent to 104 134 868 6- to 18-year-old children in the United States per year (208 369 735 over 2 waves of the NHANES), the prevalence of vitamin D deficiency among healthy-weight, overweight, obese, and severely obese children was 21%, 29%, 34%, and 49%, respectively (Fig 1A).

The prevalence of vitamin D deficiency was greater among minority, older, and female children (Table 1). There were significant racial/ethnic disparities in the prevalence of vitamin D deficiency (Fig 1B). Among those with severe obesity, the prevalence of vitamin D deficiency approached 90% in African-American children and exceeded 50% in Latino children, compared with 27% among white children. Other factors associated with a significantly higher prevalence of vitamin D deficiency included poverty, winter/spring season of

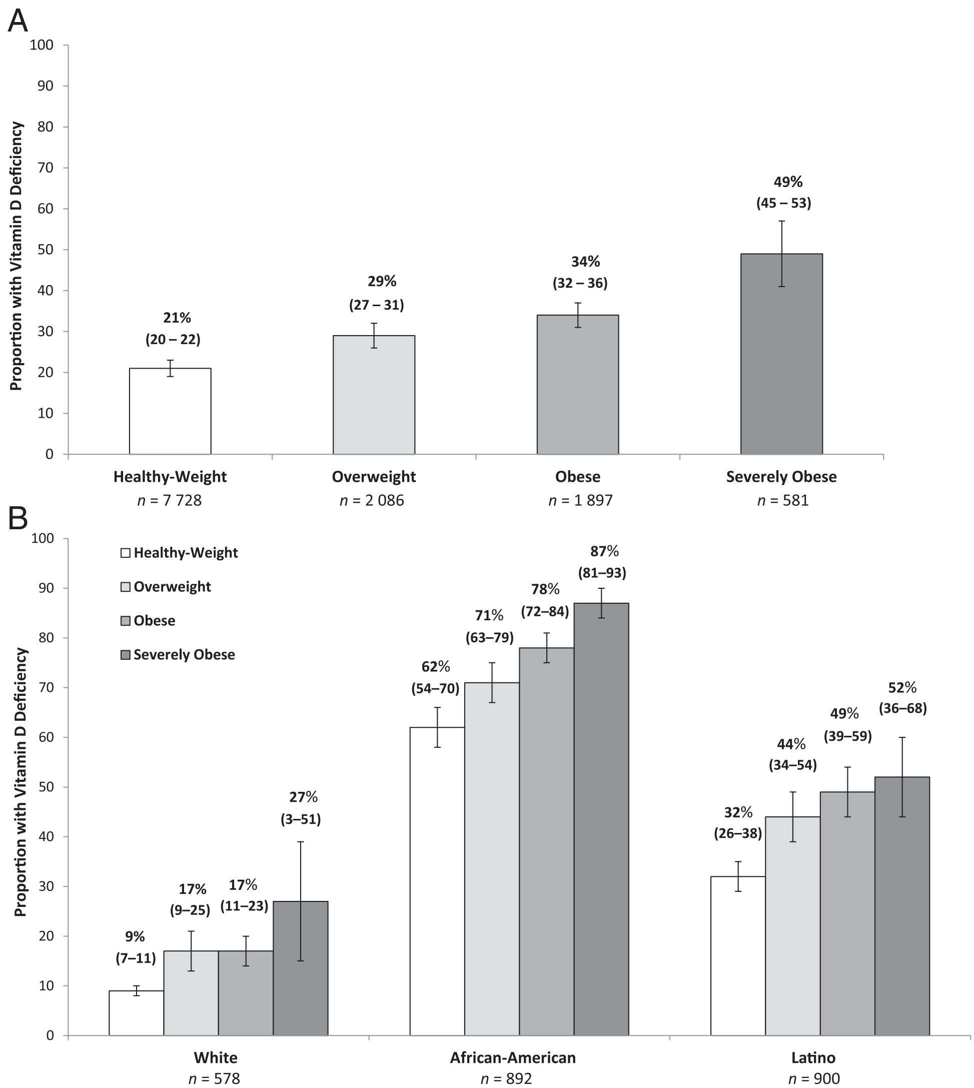

FIGURE 1

The prevalence of vitamin D deficiency[a], defined as 25-hydroxyvitamin D < 20 ng/mL, in 6- to 18-year-old children and adolescents in the NHANES 2003–2006 (weighted annualized *n* = 104 134 868). A, This figure reveals the BMI-percentile category-specific prevalence (95% confidence interval) of vitamin D deficiency among US children. The proportion of children with vitamin D deficiency increases directly with the BMI-percentile category, and almost half of severely obese US children are deficient in vitamin D. B, This figure reveals the BMI-percentile category-specific prevalence (95% confidence interval) of vitamin D deficiency by race/ethnicity. There is a high prevalence of vitamin D deficiency among minority children; and among severely obese children, ~90% of African-American and over half of Latino children are deficient in vitamin D. See Appendix 2 for mean serum 25(OH)D concentrations for each BMI-percentile category x race/ethnicity combination. [a]Vitamin D deficiency, defined as mean serum 25-hydroxyvitamin-D < 20 ng/mL.

serum collection, no vitamin D supplement use, less milk intake, greater TV/computer use, and less physical activity.

In bivariate analyses stratified by BMI-percentile category, the prevalence of vitamin D deficiency was greater among minority and older children, but there were no gender differences (Fig 1B; Table 2). No vitamin D supplement use was associated with vitamin D deficiency in over half of the severely obese children. Among overweight children, other factors significantly associated with higher prevalence of vitamin D deficiency included poverty, winter/spring season of serum collection, less milk intake, and greater TV/computer use, but not vitamin D supplement use or physical activity. Among obese children, factors associated with vitamin D deficiency included poverty, winter/spring season of serum collection, no vitamin D supplement use, and less milk intake, but not TV/computer use or physical activity.

TABLE 1 Prevalence of Vitamin D Deficiency and Mean Serum 25-Hydroxyvitamin-D Levels Among US Children (n = 12 292) by Sample Characteristics

Characteristics	Prevalence of Vitamin D Deficiency,[a,b] % (95% CI)	P
Race/ethnicity		<.01
White	12 (10–14)	—
African-American	68 (62–74)	—
Latino	38 (33–44)	—
Other	41 (26–56)	—
Age, y		<.01
6–11	15 (12–18)	—
12–18	27 (22–31)	—
Gender		<.01
Girl	28 (23–33)	—
Boy	22 (18–26)	—
Poverty status		<.01
Above poverty	21 (17–25)	—
At or below poverty	37 (30–43)	—
Season of serum collection		<.01
Summer/autumn	17 (13–21)	—
Winter/spring	36 (29–42)	—
Vitamin D supplement use		.01
Supplement use	17 (11–23)	—
No supplement use	26 (22–30)	—
Milk intake, cups/d		<.01
None to <1 cup	28 (22–33)	—
≥1 to <2 cups	21 (15–27)	—
≥2 to <3 cups	12 (8–17)	—
≥3 cups	11 (6–17)	—
TV/computer use, h/d		<.01
None to ≤2 h	16 (11–20)	—
>2 to ≤4 h	28 (23–33)	—
>4 h	32 (26–38)	—
PA, h/wk		.01
0 to <2 h	25 (21–29)	—
≥2 to <5 h	26 (22–30)	—
≥5 h	22 (17–26)	—

CI, confidence interval; PA, physical activity.

a Vitamin D deficiency, defined as serum 25(OH)D level <20 ng/mL.

b Equivalent to 104 134 868 children 6 to 18 years old in the US per year. Sample characteristics provided in Appendix 1.

In the multiple logistic regression analysis, overweight, obesity, and severe obesity were independently associated with higher risk of vitamin D deficiency (Table 3). Severely obese children had 4 times the adjusted odds of vitamin D deficiency compared with healthy weight children, after adjustment for race/ethnicity, age, gender, poverty, and season of serum collection. Adjustment for TV/computer use, physical activity, vitamin D supplement use, and milk intake cut the adjusted odds of vitamin D deficiency in half for severely obese children and resulted in similar adjusted odds of vitamin D deficiency for the 3 BMI-percentile categories.

In multivariable logistic regression analyses stratified by BMI-percentile categories, African-American race/ethnicity, Latino race/ethnicity, and older age were associated with significantly greater adjusted odds of vitamin D deficiency for all BMI-percentile categories (Table 4). BMI-percentile category-specific factors associated with vitamin D deficiency also were identified. For overweight children, additional factors included female gender, poverty, and TV/computer use >2 hours per day, whereas ≥2 cups of milk per day was associated with decreased odds of vitamin D deficiency. For obese/severely obese children, other race/ethnicity, season of serum collection, no vitamin D supplement use, TV/computer use >2 hours per day, and physical activity <2 hours per week were associated with higher odds and ≥3 cups of milk per day with lower odds of vitamin D deficiency.

DISCUSSION

This is the first study, to our knowledge, to provide nationally representative estimates of the BMI-percentile category-specific prevalence of and risk factors associated with vitamin D deficiency in 6 to 18-year-old US children.

Study findings revealed a high prevalence and adjusted odds of vitamin D deficiency among overweight, obese, and severely obese children. Children with severe obesity appear to be particularly at risk. One in 2 children with severe obesity were vitamin D deficient; even after adjustment, these children had more than double the odds of vitamin D deficiency compared with healthy-weight children. These findings are consistent with the high prevalence reported in regional studies of children seen at individual obesity treatment centers (50%–100%) and a study of British children (39% among children with a BMI ≥ 85th percentile).[5,13,23,29]

Substantial racial/ethnic disparities were noted in the prevalence of vitamin D deficiency among all BMI-percentile categories. The high prevalence of vitamin D deficiency among severely obese minority children is noteworthy. Only about one-tenth of severely obese African-American children do not have vitamin D deficiency. Minority race/ethnicity and darker skin pigmentation are known risk factors for vitamin D deficiency.[30] Other previously reported factors that may underlie racial/ethnic disparities in vitamin D levels include differences in milk consumption,[28] body fat distribution,[6,31] and hormone levels, such as leptin and adiponectin.[4] Genetic differences in vitamin D receptors might also play a role.[1] The high prevalence among obese minority children suggests that routinely screening for and treating vitamin D deficiency in these children might be particularly useful.

TABLE 2 BMI-Percentile Category-Specific Prevalence of Vitamin D Deficiency Among US Children by Sample Characteristics

Characteristics	BMI-Percentile Category-Specific Prevalence (95% CI) of Vitamin D Deficiency[a]					
	Overweight, $N = 2086$	P	Obese, $n = 1897$	P	Severely Obese, $n = 581$	P
Age, y		.01		<.01		<.01
6–11	17 (11–23)	—	18 (14–22)	—	31 (21–41)	—
12–18	32 (26–38)	—	37 (31–43)	—	54 (45–63)	—
Gender		.07		.05		.3
Girl	33 (27–39)	—	38 (30–46)	—	56 (40–72)	—
Boy	25 (19–31)	—	29 (23–35)	—	46 (36–56)	—
Poverty status		<.01		<.01		.8
At or below poverty	49 (39–59)	—	53 (41–65)	—	51 (33–69)	—
Above poverty	23 (17–29)	—	29 (23–35)	—	48 (28–68)	—
Season of serum collection		<.01		<.01		.2
Summer/autumn	23 (17–29)	—	23 (17–29)	—	42 (20–64)	—
Winter/spring	37 (31–43)	—	51 (41–61)	—	61 (45–77)	—
Vitamin D supplement use		.2		<.01		<.01
Yes	23 (14–33)	—	11 (4–18)	—	13 (0–25)	—
No	30 (24–36)	—	38 (32–44)	—	53 (37–69)	—
Milk intake, milk-cup equivalents/d		<.01		<.01		.05
None to <1 cup	36 (28–44)	—	38 (30–46)	—	39 (21–57)	—
≥1 to <2	23 (11–35)	—	28 (14–42)	—	69 (47–91)	—
≥2 to <3	8 (2–14)	—	14 (8–20)	—	34 (10–58)	—
≥3	11 (3–19)	—	5 (0–11)	—	37 (0–75)	—
TV/Computer use, h/d		<.01		.2		.2
None to ≤2 h	15 (8–22)	—	27 (19–36)	—	35 (15–55)	—
>2 to ≤ 4 h	31 (21–41)	—	33 (21–44)	—	54 (42–67)	—
>4 h	41 (30–52)	—	39 (30–47)	—	52 (31–74)	—
Physical activity, h/wk		.05		.3		<.01
0 to <2 h	33 (24–41)	—	36 (28–43)	—	54 (35–73)	—
≥ 2 to <5 h	30 (23–37)	—	34 (28–41)	—	41 (21–62)	—
≥5 h	23 (19–28)	—	30 (22–38)	—	41 (27–55)	—

CI, confidence interval.

[a] Vitamin D deficiency, defined as serum 25(OH)D level < 20 ng/mL.

TABLE 3 Multivariable Analyses of the Association of BMI-Percentile-Category With Vitamin D Deficiency Among US Children

Characteristics	Adjusted Odds Ratio (95% CI) of Vitamin D Deficiency			
	Model 1[a]	Model 2[b]	Model 3[c]	Full Model[d]
BMI-percentile category				
Healthy weight	Referent	Referent	Referent	Referent
Overweight	1.8 (1.3–2.4)	1.7 (1.3–2.4)	1.7 (1.2–2.4)	1.7 (1.2–2.4)
Obese	2.2 (1.6–2.9)	2.1 (1.6–2.9)	1.8 (1.3–2.5)	1.8 (1.3–2.5)
Severely obese	4.0 (1.8–8.9)	3.7 (1.6–8.1)	2.5 (2.1–5.0)	2.3 (1.1–4.5)

CI, confidence interval.

[a] Model 1 adjusted for race/ethnicity, age, gender, poverty, and season of serum collection.

[b] Model 2 adjusted for variables in model 1, plus TV/computer use and physical activity.

[c] Model 3 adjusted for variables in model 1, plus vitamin D supplementation and milk intake.

[d] Full model adjusted for all variables, including those in model 1 plus TV/computer use, physical activity, vitamin D supplementation, and milk intake.

also may be protective. These findings underscore the importance of the American Academy of Pediatrics recommendation to counsel children on limiting TV/computer use to ≤2 hours per day while substituting outdoor activity.[31] The findings also support an additional recommendation for overweight children to drink at least 2 servings of vitamin-D-fortified low-fat milk per day. And, although additional vitamin D supplementation may not be required to achieve adequate serum vitamin D levels in healthy-weight children,[16,17] children with obesity may need additional supplementation above the dose recommended by the Institute of Medicine.[16,17,31] Theories regarding the reasons for the greater need for supplemental vitamin D in obese individuals include greater sequestration of vitamin D in fat stores and differences in 25-hydroxyvitamin-D metabolism.[3,31]

Certain study limitations should be noted. BMI-percentile categories were used as proxies for greater degrees of adiposity because of their clinical usefulness, but BMI is an imperfect proxy for adiposity. Although the data set analyzed was the most recently available, these 2003–2006 NHANES data are several years old; at the time of the analysis, the 2007–2008 NHANES vitamin D data had not been released. In addition, the cut point for vitamin D deficiency used in this study was chosen in the absence of data on the optimal level of vitamin D to prevent adverse outcomes. In young children, parathyroid hormone changes and bone density cannot be used as functional outcomes to determine vitamin D deficiency.[33] The dose of vitamin D supplementation was not available for individuals in the 2003–2004 and 2005–2006 NHANES data sets. Further research is warranted to determine the vitamin D dose needed to prevent and treat vitamin D deficiency in obese children. And, because sunlight is the

This study also identified modifiable factors that were independently associated with vitamin D deficiency among overweight and obese children, each of which can be ascertained by a patient history. Drinking at least 2 to 3 cups of milk per day and limiting TV/computer use to ≤2 hours per day (by substituting more outdoor activity) may protect against vitamin D deficiency. For obese children, supplemental vitamin D and ≥2 hours per day of physical activity

TABLE 4 Multivariable Risk Assessment Analysis of Factors Associated With Vitamin D Deficiency in Overweight and Obese US Children

Characteristics	Adjusted Odds Ratio (95% CI) of Vitamin D Deficiency[a]			
	Overweight	Obese	Severely Obese	Obese/Severely Obese
Race/ethnicity				
White	Referent	Referent	Referent	Referent
African-American	15.7 (6.9–35.9)	28.3 (14.4–55.7)	115.5 (23.7–562.5)	35.3 (18.9–65.9)
Latino	3.7 (1.3–11.1)	4.0 (1.7–9.5)	8.4 (1.9–37.2)	4.7 (2.0–11.0)
Other	4.1 (0.6–26.9)	4.9 (1.3–18.0)	343 (13.3–>999)	6.5 (2.0–21.6)
Older age (12–18 y)[b]	2.8 (1.2–6.4)	3.8 (1.7–8.6)	10.3 (2.7–40.1)	3.8 (1.9–7.6)
Girl gender[c]	2.1 (1.1–3.8)	1.5 (0.7–3.1)	6.0 (1.6–22.0)	1.7 (0.9–3.4)
Below poverty[d]	2.8 (1.3–5.9)	2.2 (0.9–5.2)	0.6 (0.2–1.6)	1.6 (0.8–3.3)
Winter/spring season of serum collection[e]	1.4 (0.8–2.3)	2.0 (0.9–4.3)	3.6 (0.9–14.6)	2.0 (1.1–3.8)
No vitamin D supplement use[f]	0.6 (0.2–1.6)	3.5 (1.5–8.1)	122.7 (6.6–>999)	5.1 (2.5–10.6)
Milk intake				
None to <1 cup	Referent	Referent	Referent	Referent
≥1 to <2 cups	0.7 (0.3–1.5)	1.1 (0.4–3.4)	0.9 (0.2–4.7)	1.3 (0.6–2.9)
≥2 to <3 cups	0.2 (0.1–0.5)	0.6 (0.2–1.5)	0.5 (0.1–3.8)	0.6 (0.3–1.5)
≥3 cups	0.3 (0.1–0.7)	0.1 (0.03–0.4)	0.4 (0.2–1.2)	0.2 (0.1–0.4)
TV/computer use, h/d				
None to ≤2 h	Referent	Referent	Referent	Referent
>2 to ≤4 h	2.7 (1.1–6.3)	2.0 (0.8–5.3)	3.7 (1.1–12.2)	2.3 (1.03–5.2)
>4 h	2.9 (1.1–7.6)	2.3 (0.9–5.8)	2.1 (0.6–7.0)	2.4 (1.1–5.1)
Physical activity, h/wk				
≥5	Referent	Referent	Referent	Referent
≥2 to <5 h	1.1 (0.6–2.0)	1.4 (0.8–2.6)	1.0 (0.3–2.9)	1.4 (0.9–2.4)
None to <2 h	1.3 (0.8–2.0)	1.7 (0.8–3.6)	5.5 (1.9–16.2)	1.9 (1.01–3.6)

CI, confidence interval.

a Vitamin D deficiency, defined as 25-hydroxyvitamin D<20 ng/mL.

b Compared with younger age (6–11 y).

c Compared with boy gender.

d Compared with above poverty.

e Compared with summer/autumn season of serum collection.

f Compared with vitamin D supplement use.

primary source of vitamin D, a measure of outdoor activity would be ideal, but does not exist in the NHANES for all age groups. Finally, the possible association of vitamin D deficiency with adverse skeletal conditions and cardiometabolic risk factors in overweight and obese children could not be examined, because the NHANES does not collect data on functional outcomes, such as fracture risk, and only collects data regarding cardiometabolic risk factors in limited age ranges (primarily ≥12-year-old children). Additional research is needed assessing the association of vitamin D deficiency with functional outcomes, including proxy measures of bone strength that track with functional outcomes[34] and cardiometabolic risk factors.

Strengths of this study include the clinically useful prevalence estimates, population-based national sample, and adjustment for dietary and activity factors known to be associated with both obesity and vitamin D deficiency. Until now, a practicing clinician could not determine a pretest probability of vitamin D deficiency based upon a child's BMI-percentile category. Previous data on the prevalence of vitamin D deficiency in obese children have been subject to limitations inherent in using single-center and referral-based samples. Prevalence estimates from this study are based on sampling weights and generalize to the entire population of US children. Finally, study findings were adjusted for important confounders, including diet and activity factors.

CONCLUSIONS

A high prevalence and adjusted odds of vitamin D deficiency were found among overweight, obese, and severely obese US children, and sizeable racial/ethnic disparities were noted. Modifiable, independent risk factors for vitamin D deficiency were identified among both overweight and obese/severely obese children, including drinking at least 2 to 3 cups per day of vitamin D-fortified milk, restricting TV/computer use to ≤2 hours per day, and being physically active ≥2 hours per week. Obese children may require additional vitamin D supplementation to prevent vitamin D deficiency. Further studies are needed to determine the clinical relevance of low vitamin D levels among overweight/obese children, including whether there is a causal relationship between vitamin D deficiency and obesity-associatedcardiometabolic conditions, as well as skeletal conditions, such as slipped capital femoral epiphysis, fractures, and the significantly lower height-adjusted bone mineral content in obese children with fracture histories.[35] For now, the study findings suggest the need for vigilance in vitamin D deficiency screening and treatment of obese and minority children.

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APPENDIX 1 Characteristics of 6- to 18-Year-Old US Children (NHANES 2003–2006) by BMI-Percentile Category

Characteristics	Healthy-Weight, Proportion (95% CI)	Overweight, Proportion (95% CI)	Obese, Proportion (95% CI)	Severely Obese, Proportion (95% CI)	*P*
Race/ethnicity					<.01
White	69 (6–73)	67 (58–76)	62 (54–70)	52 (41–62)	—
African-American	11 (8–15)	12 (8–17)	15 (11–18)	29 (21–37)	—
Latino	13 (10–17)	17 (11–23)	19 (14–25)	17 (11–23)	—
Other	7 (5–9)	4 (2–5)	4 (1–6)	2 (0–4)	—
Age, y					.9
6–11	19 (16–23)	18 (14–22)	20 (16–24)	20 (15–24)	—
12–18	81 (77–84)	82 (78–86)	80 (76–84)	80 (76–85)	—
Gender					.05
Female	47 (44–50)	47 (41–53)	49 (43–54)	31 (23–39)	—
Male	53 (50–56)	53 (47–59)	51 (46–57)	69 (61–77)	—
Poverty status					.01
At or below poverty	18 (15–21)	22 (16–28)	22 (16–27)	32 (22–41)	—
Above poverty	82 (79–85)	78 (72–84)	78 (73–84)	68 (59–78)	—
Season of serum collection					.7
Summer/autumn	59 (49–70)	58 (47–68)	62 (52–71)	62 (48–76)	—
Winter/spring	41 (30–51)	42 (32–53)	38 (29–48)	38 (24–52)	—
Vitamin D supplement use					.08
Yes	20 (17–24)	16 (12–20)	15 (9–21)	9 (2–17)	—
No	80 (76–83)	84 (80–88)	85 (78–91)	91 (83–98)	—
Milk intake, milk-cup equivalents/d					.2
None to <1 cup	60 (56–64)	59 (49–68)	56 (48–63)	73 (65–81)	—
≥1 to <2	14 (12–16)	12 (7–17)	13 (7–19)	13 (7–20)	—
≥2 to <3	20 (17–24)	20 (14–27)	22 (17–27)	10 (5–15)	—
≥3	5 (3–7)	8 (5–11)	9 (3–15)	3 (1–6)	—
TV/computer use, h/d					<.01
None to ≤2 h	42 (38–45)	37 (31–43)	31 (25–36)	22 (13–30)	—
>2 to ≤4 h	24 (21–26)	23 (19–27)	25 (19–31)	22 (14–30)	—
>4 h	35 (32–37)	40 (34–46)	44 (38–51)	56 (46–66)	—
Physical activity, h/wk					<.01
0 to <2 h	35 (33–38)	34 (30–37)	34 (31–38)	26 (19–32)	—
≥2 to <5 h	30 (28–31)	35 (32–38)	33 (29–37)	42 (35–48)	—
≥5 h	35 (32–38)	31 (27–36)	33 (29–36)	32 (26–39)	—

CI, confidence interval.

APPENDIX 2 Prevalence of Vitamin D Severe Deficiency and Insufficiency, and Mean Serum 25-Hydroxyvitamin-D Levels Among US Children by BMI-Percentile-Category and Race/Ethnicity

Characteristics	Prevalence (95% CI) of Vitamin D				Mean 25(OH)D, ng/mL (95% CI), *n* = 12 292	*P*
	Severe Deficiency, 25(OH)D <12 ng/mL, *n* = 1433	*P*	Insufficiency, 25(OH)D <30 ng/mL, *n* = 10 398	*P*		
BMI-percentile category		<.01		<.01		<.01
Healthy-weight	4 (2–6)	—	69 (64–73)	—	26 (25–27)	—
Overweight	5 (3–6)	—	79 (73–85)	—	24 (23–26)	—
Obese	9 (7–12)	—	86 (80–92)	—	23 (21–24)	—
Severely obese	17 (0–24)	—	92 (85–99)	—	19 (17–22)	—
Race/ethnicity						
White		<.01		<.01		<.01
All	0.6 (0.1–1.2)	—	64 (59–68)	—	28 (27–29)	—
Healthy-weight	0.2 (0–0.4)	—	71 (62–79)	—	29 (28–30)	—
Overweight	0.8 (0–1.8)	—	78 (68–88)	—	27 (25–29)	—
Obese	2.5 (0–6)	—	87 (73–100)	—	26 (24–27)	—
Severely obese	3.2 (0–8.1)	—	91 (89–93)	—	23 (20–26)	—
African-American		<.01		<.01		<.01
All	26 (20–31)	—	97 (96–98)	—	17 (16–18)	—
Healthy-weight	22 (16–27)	—	96 (94–97)	—	18 (17–19)	—
Overweight	23 (16–29)	—	98 (97–100)	—	16 (15–18)	—
Obese	36 (25–47)	—	99 (98–100)	—	14 (13–15)	—
Severely obese	43 (31–56)	—	99 (97–100)	—	13 (12–14)	—
Latino		<.01		<.01		<.01
All	7 (4–9)	—	91 (89–93)	—	22 (21–22)	—
Healthy-weight	5 (3–7)	—	88 (85–90)	—	23 (22–23)	—
Overweight	7 (3–11)	—	95 (92–98)	—	21 (19–22)	—
Obese	10 (4–15)	—	98 (97–98)	—	20 (18–21)	—
Severely obese	16 (6–26)	—	94 (89–100)	—	19 (17–21)	—
Other		.4		.01		.3
All	11 (1–21)	—	88 (79–97)	—	21 (19–23)	—
Healthy-weight	11 (0–23)	—	85 (74–96)	—	22 (19–24)	—
Overweight	3 (0–7)	—	96 (90–100)	—	21 (19–24)	—
Obese	18 (0–35)	—	99 (97–100)	—	19 (15–23)	—
Severely obese	17 (0–47)	—	88 (65–100)	—	21 (14–27)	—

CI, confidence interval.

Prevalence of Vitamin D Deficiency Among Overweight and Obese US Children

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