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Vitamin D Deficiency in School-Age Children Is Associated with Sociodemographic and Lifestyle Factors[1–3]

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Abstract

Background: There is concern about a reemergence of vitamin D deficiency in children in developed countries.

Objectives: The aims of this study were to describe vitamin D status in the Generation R study, a large multiethnic cohort of 6-y-old children in The Netherlands, and to examine sociodemographic, lifestyle, and dietary determinants of vitamin D deficiency.

Methods: We measured serum 25-hydroxyvitamin D [25(OH)D] concentrations in 4167 children aged 6 y and defined deficiency following recommended cutoffs. We examined the associations between subject characteristics and vitamin D deficiency with the use of multivariable logistic regression analyses.

Results: Serum 25(OH)D concentrations ranged from 4 to 211 nmol/L (median: 64 nmol/L), with 6.2% of the children having severely deficient (<25 nmol/L), 23.6% deficient (25 to <50 nmol/L), 36.5% sufficient (50 to <75 nmol/L), and 33.7% optimal (≥75 nmol/L) 25(OH)D concentrations. The prevalence of vitamin D deficiency [25(OH)D <50 nmol/L] was higher in winter (51.3%) than in summer (10.3%); and higher in African, Asian, Turkish, and Moroccan children (54.5%) than in those with a Dutch or other Western ethnic background (17.6%). In multivariable models, several factors were associated with vitamin D deficiency, including household income (OR: 1.74; 95% CI: 1.34, 2.27 for low vs. high income), child age (OR: 1.39; 95% CI: 1.20, 1.62 per year), child television watching (OR: 1.32; 95% CI: 1.06, 1.64 for ≥2 vs. <2 h/d), and playing outside (OR: 0.71; 95% CI: 0.57, 0.89 for ≥1 vs. <1 h/d). In a subgroup with dietary data (n = 1915), vitamin D deficiency was associated with a lower diet quality, but not with vitamin D intake or supplement use in early childhood.

Conclusions: Suboptimal vitamin D status is common among 6-y-old children in The Netherlands, especially among non-Western children and in winter and spring. Important modifiable factors associated with vitamin D deficiency were overall diet quality, sedentary behavior, and playing outside. *J Nutr* 2015;145:791–8.

Keywords: 25-hydroxyvitamin D, vitamin D deficiency, predictors, determinants, children, cohort

Introduction

In recent years, vitamin D status and its potential health effects have received much attention in research (1–3). Vitamin D is important for bone health because it is required for calcium absorption from the gut; hence, vitamin D deficiency is associated with rickets in children and osteomalacia in adults (3). In addition to skeletal health, studies have suggested that vitamin D deficiency is associated with several other health risks in adults, including cognitive decline, autoimmune disease, cancer, cardiovascular disease, and mortality (4–6), although evidence is not consistent (7). In children, vitamin D has been shown to be important for maturation of the immune system, and higher vitamin D concentrations have been linked to a lower prevalence of asthma and a reduced risk of respiratory infections (8, 9).

There has been concern about a reemergence of vitamin D deficiency in children living in developed countries, with insufficient vitamin D concentrations reported in up to 70% of children in general populations (aged 1–21 y) (10–12). Vitamin D is a nutrient, but vitamin D status depends mainly on cutaneous production (3). Because vitamin D synthesis depends

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[3] Supplemental Figure 1 and Supplemental Tables 1–3 are available from the "Online Supporting Material" link in the online posting of the article and from the same link in the online table of contents at http://jn.nutrition.org.
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on exposure to sunlight, changes in lifestyle such as spending much time indoors and using sun protection, are considered to be important causes of vitamin D insufficiency (1, 3). The increase in prevalence of vitamin D deficiency, in combination with the widespread report of the involvement of vitamin D in various health aspects, makes vitamin D status of important public health interest (2). To better identify children at high risk and to define strategies to improve vitamin D status, it is important to recognize sociodemographic and lifestyle determinants of vitamin D status. A number of previous studies have evaluated vitamin D status and its determinants in young children, but most of these had limited sample sizes (10, 13–15) and were performed in children with a Western ethnic background only, while immigrants may be at increased risk of vitamin D deficiency (16). Only 2 previous studies have examined determinants of vitamin D status in large groups of children (aged 1–17 and 1–21 y), but both studies had a cross-sectional design and measured a limited number of potential determinants (11, 12).

Therefore, our aims were to describe vitamin D status in a large multiethnic population of 6-y-old children born in Rotterdam, The Netherlands, to determine the prevalence of vitamin D deficiency, and to identify parental and child sociodemographic and lifestyle factors related to child vitamin D status. In a subgroup of children with dietary data, we also evaluated the associations between dietary characteristics in early childhood and subsequent vitamin D status at age 6 y.

Methods

Design. This study was embedded in the Generation R Study, a population-based prospective cohort study from pregnancy onward in the city of Rotterdam (52° north latitude), The Netherlands (17). The study protocol was approved by the Medical Ethical Committee of Erasmus University Medical Center, Rotterdam, and all participants provided written consent. Mothers living in the study area with an expected delivery date between April 2002 and January 2006 were eligible. In total, 9778 mothers were enrolled in the study and gave birth to 9749 live-born children. At the age of 6 y, 8305 of these children were still participating in the study (17), of whom 6690 visited the research center. During this visit, we collected a blood sample in 4473 children who provided consent for venous puncture and we successfully assessed 25-hydroxyvitamin D [25(OH)D] concentrations for 4167 children. Further details on the population for analysis are provided in **Supplemental Figure 1**.

25(OH)D concentrations. At a median age of 6.0 y (95% range 5.6–7.9), nonfasting blood samples were drawn by antecubital venipuncture and stored at −80°C until analysis (18). Measurements of 25(OH)D were conducted at the Endocrine Laboratory of the VU University Medical Center, Amsterdam, as described before (19). Serum 25(OH)D was measured with the use of isotope dilution online solid phase extraction liquid chromatography-tandem mass spectrometry (19–21), a highly sensitive and specific method for the quantification of 25(OH)D (19–21) that is the recommended method for vitamin D assessment in epidemiologic studies (21). The limit of quantitation was 4.0 nmol/L; intra-assay CV was <6%, and interassay CV was <8% for concentrations between 25 and 180 nmol/L.

Optimal vitamin D concentrations for health remain a subject of debate (3). On the basis of recommendations and previous studies in pediatric populations, we defined the following categories: <25 nmol/L (<10 μg/L), severely deficient; 25 to <50 nmol/L (10 to <20 μg/L), deficient; 50 to <75 nmol/L (20 to <30 μg/L), sufficient; and ≥75 nmol/L (≥30 μg/L), optimal (1, 11, 14, 15, 22–24).

Parental characteristics. We identified potential determinants of vitamin D deficiency in children on the basis of previous literature (10–15). Information on parity and on maternal smoking, alcohol use, and folic acid supplementation during pregnancy were obtained with questionnaires. Information on maternal age, marital status, education, parental employment, net household income, and smoking in the household was obtained from a questionnaire at the child's age of 6 y. Maternal height and weight were measured around the child's age of 6 y, and BMI (kilograms per meter squared) was calculated.

Infant characteristics. Information on the child's sex, birth weight, and gestational age at birth was available from medical records and hospital registries. Sex- and gestational age–specific SD scores for birth weight were calculated with Swedish reference data (25). Information on child ethnicity was obtained with a questionnaire and was defined based on country of birth of the parents (26). We categorized ethnicity into Dutch and other Western (European, American, and Oceanian); Turkish and Moroccan; African (Cape Verdean, other African, Surinamese-Creole, and Dutch Antillean); and Asian (Indonesian, other Asian, and Surinamese-Hindu) according to the largest ethnic groups in our study population and similarities in skin color and cultural background (**Supplemental Table 1**). Information on breastfeeding was obtained from delivery reports and postnatal questionnaires.

Child characteristics. At the age of 6 y, child weight and height were measured without shoes and heavy clothing at the research center, and BMI was calculated. Sex- and age-specific SD scores for weight and height were calculated with the use of Dutch growth charts (27). Child weight status (underweight, normal weight, overweight, or obese) was defined according to international age- and sex-specific BMI cutoffs (28). Information on the amount of sunlight in Rotterdam was obtained from the Royal Netherlands Meteorological Institute, and average amount of sunlight in the 28 d before blood sampling was estimated for each child (29). Information on duration of television watching and computer use, participation in sports (yes or no), means of transportation to school, and playing outside during daytime at the age of 6 y was obtained with a questionnaire.

Dietary characteristics. Dietary data were available for a subgroup of children (n = 1915). For these children, mothers had received a validated semiquantitative FFQ at a median child age of 12.9 mo (95% range 12.2–19.0) (30). We calculated mean daily intakes of vitamin D and of the following food groups: margarines and cooking fats (fortified with vitamin D), dairy (not fortified in The Netherlands), infant formula (fortified with vitamin D), and fish and shellfish (naturally rich in vitamin D). Information on vitamin supplement use was available from the same FFQ. Vitamin D supplement use was defined (yes or no), reporting yes if using vitamin D supplements, vitamin A and D supplements, or multivitamin supplements. We used a previously defined child diet quality score as a measure of overall diet quality (31).

Statistical analysis. Differences in parental or child characteristics between vitamin D categories were assessed with 1-factor ANOVA or Kruskal Wallis tests for continuous variables and chi-square tests for categoric variables. We performed logistic regression models to examine the associations of sociodemographic and lifestyle factors with 25(OH)D deficiency (<50 nmol/L). All variables with $P < 0.10$ in univariable models were included in one multivariable model. To retain only the strongest determinants, we performed a stepwise backward elimination procedure on the full multivariable model, with $P < 0.10$ as endpoint. We performed separate logistic regression models in the subgroup of children with dietary data (n = 1915). These models were adjusted for the most important sociodemographic and lifestyle determinants of vitamin D deficiency that were identified in the stepwise regression analysis in the full group (i.e., factors with $P < 0.001$ in the final multivariable model). We performed sensitivity analyses in which we used 25 nmol/L and 75 nmol/L as cutoffs to define 25(OH)D deficiency. Because non-Western populations may have other factors associated with vitamin D status, we performed sensitivity analyses that included Dutch and other Western children only. Furthermore, we evaluated statistical interaction by adding the product terms of the different ethnic groups and other covariates (i.e., season, child weight status, maternal education, and household income) to the models with vitamin D

deficiency as an outcome. Stratified analyses were conducted if the interaction term was significant ($P < 0.05$).

To reduce potential bias associated with missing data, we performed multiple imputations of missing covariates based on the correlation between the variable with missing values and other subject characteristics (32). Data were imputed ($n = 10$ imputations) according to the fully conditional specification method (predictive mean matching), assuming no monotone missing pattern. Analyses were performed in the original dataset and in the imputed datasets. Because we observed similar effect estimates, we only present the results based on imputed datasets. Statistical analyses were performed with SPSS version 21 for Windows.

Results

Participant characteristics and 25(OH)D status. Serum 25(OH)D concentrations ranged from 4 to 211 nmol/L, with a median of 64 nmol/L (**Table 1**). Of all children, 6.2% were severely vitamin D–deficient [25(OH)D <25 nmol/L], 23.6% were vitamin D–deficient [25(OH)D 25 to <50 nmol/L], 36.5% had sufficient concentrations [25(OH)D 50 to <75 nmol/L], and only 33.7% had optimal concentrations [25(OH)D ≥75 nmol/L]. The prevalence of vitamin D deficiency [25(OH)D <50 nmol/L] was highest in winter (51.3%) and lowest in summer (10.3%) (**Figure 1**A). Vitamin D deficiency was also highly prevalent in non-Western children: 54.5% of Turkish and Moroccan, 55.5% of African, and 51.9% of Asian children were vitamin D–deficient, compared with only 17.6% of the Dutch and other Western children (Figure 1B). The amount of sunlight in the month before the blood draw was higher in those with sufficient or optimal vitamin D status than in those with deficiency (**Supplemental Table 2**). Nonresponse analyses showed that children who visited the research center without available blood samples ($n = 2523$) were more often girls, slightly younger, and shorter, had a lower weight, and more often had mothers with a lower educational background or lower household income compared with children with available blood samples (results not shown), although these differences were very small.

TABLE 1 Characteristics of the children and their parents[1]

	n	Values
Child characteristics		
Age, y	4167	6.0 (5.7–8.0)
Male	4167	51.5
Ethnicity	4011	
Dutch and other Western		69.0
Moroccan and Turkish		13.4
African		11.4
Asian		6.3
Weight, kg	4159	22.6 (17.6–34.6)
Height, cm	4159	119.8 ± 6.0
Participation in sports	3526	45.6
TV watching ≥2h/d	3257	19.5
Computer use ≥1h/d	3249	7.3
Amount of sunlight in the month before blood draw, h/d	4167	5.0 (1.3–9.5)
Season of blood sampling	4167	
Winter		21.5
Spring		28.3
Summer		25.4
Fall		24.7
25(OH)D concentration, nmol/L	4167	64 (18–131)
25(OH)D status	4167	
Severely deficient (<25 nmol/L)		6.2
Deficient (25 to <50 nmol/L)		23.6
Sufficient (50 to <75 nmol/L)		36.5
Optimal (≥75 nmol/L)		33.7
Parental characteristics		
Maternal age, y	4090	37.3 ± 4.9
Maternal educational level	3550	
Primary		4.0
Secondary		38.7
Higher		57.3
Household income	3370	
<2000 euros/mo		24.0
2000–3200 euros/mo		25.0
>3200 euros/mo		51.1

[1] Values are percentages for categorical variables, means ± SDs for continuous variables with a normal distribution, or medians (95% ranges) for continuous variables with a skewed distribution. 25(OH)D, 25-hydroxyvitamin D.

Sociodemographic and lifestyle determinants of vitamin D deficiency. In the full multivariable model after the backward elimination procedure, several child and parental sociodemographic and lifestyle factors were associated with vitamin D deficiency (<50 nmol/L) in children (**Table 2**). Risk of vitamin D deficiency was higher in winter and spring [(OR: 3.38; 95% CI: 2.31, 4.93) and (OR: 4.50; 95% CI: 3.42, 5.94), respectively, compared with summer] and in children with a non-Western ethnicity [ORs (95% CIs) ranged from 3.07 (2.23, 4.23) for Turkish and Moroccan children to 4.00 (2.85, 5.62) for Asian children compared with children with a Dutch or other Western background]. Also, children's higher age, lower birth weight, current underweight, more television watching, playing less outside, and biking less to school were associated with higher risk of vitamin D deficiency. In contrast, child sex, height, participation in sports, or breastfeeding history were not associated with vitamin D deficiency.

Furthermore, the risk of vitamin D deficiency was higher in children of mothers who were younger, multiparous, had a higher BMI, did not use folic acid supplements during pregnancy, or had a lower household income. Maternal education, marital status, and smoking or alcohol use during pregnancy were not associated with child vitamin D deficiency.

Multivariable models with continuous 25(OH)D concentrations or with different cutoffs to define vitamin D deficiency as an outcome revealed similar determinants (data not shown). We observed no significant interactions between ethnicity and season, child weight status, maternal education, or household income on vitamin D deficiency. Results from the sensitivity analysis including Dutch and other Western children only were similar to those for the whole group (**Supplemental Table 3**).

Dietary characteristics and 25(OH)D status. The associations between dietary characteristics in early childhood and vitamin D deficiency (<50 nmol/L) at age 6 y ($n = 1915$) are presented in **Table 3**. After adjustment for sociodemographic and lifestyle factors, the risk of vitamin D deficiency was lower in children with a higher diet quality score (OR: 0.87; 95% CI: 0.78, 0.97 per point increase in diet score) and in children with a high intake of margarines and cooking fats (OR: 0.72; 95% CI: 0.51, 1.00 for highest vs. lowest tertile). Intakes of dairy and cheese, fish and shellfish, infant formula, or vitamin D or vitamin D supplement use in early childhood were not associated with vitamin D status.

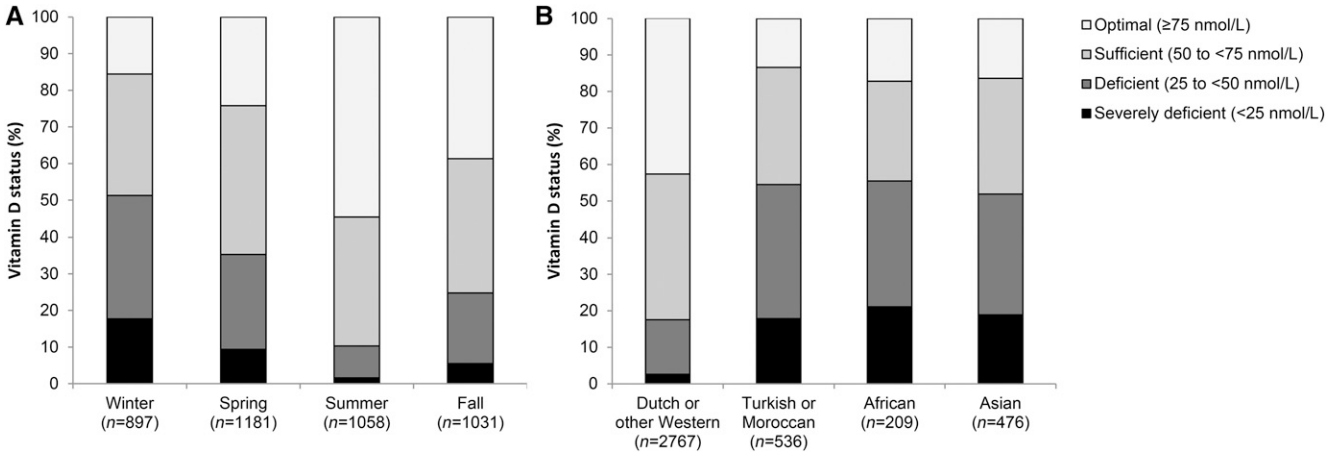

FIGURE 1 Serum 25-hydroxyvitamin D concentrations in different seasons (A) and in different ethnic groups (B) in children aged 6 y (n = 4167).

Discussion

In this large population-based cohort study, we observed a high prevalence of vitamin D deficiency in 6-y-old children, especially among non-Western children and in winter and spring. Other important determinants of vitamin D deficiency included a higher child age, more television watching, less playing outside, less biking to school, lower maternal age, lower household income, multiparity, and higher maternal BMI. To the best of our knowledge, this is the largest study that assessed vitamin D status and its determinants in children in The Netherlands, and among the first large studies worldwide (11, 12).

In our population, 30% of all children were vitamin D–deficient (<50 nmol/L) and 66% had suboptimal vitamin D concentrations (<75 nmol/L). This prevalence is comparable to those observed in previous studies. In a large (n = 6275) survey among a multiethnic group of US children (aged 1–21 y), 70% had suboptimal 25(OH)D concentrations (<75 nmol/L) (11), and in a study in the United Kingdom (n = 1102), 35% of the 4- to 8-y-old children were vitamin D–deficient (<50 nmol/L) (33). In contrast, 2 studies (n = 380 and 781) in US toddlers up to the age of 3 y reported prevalences of vitamin D deficiency (<50 nmol/L) of only 12% and 15%, respectively (10, 14). This may be explained by the younger age of these children, because previous studies reported that younger children generally have higher vitamin D concentrations (14, 33, 34). Also, within our study population, we observed that older children had a higher risk of vitamin D deficiency. Potential explanations could be that older children less often receive vitamin D supplements or that they spend less time playing outdoors (33).

As expected, we observed large differences in vitamin D concentrations between children of different ethnicities (35–37). Previous small studies in The Netherlands also reported a higher prevalence of vitamin D deficiency in immigrant children (35), in children from asylum seekers (36), and in Turkish and Moroccan children (37) compared with native Dutch children. Similarly, a large survey in 10,015 children in Germany reported a higher prevalence of deficiency in 3- to 17-y-old immigrant children (76% <50 nmol/L) compared with nonimmigrant children (62%) (12). Differences in vitamin D concentrations between different ethnicities might be explained by higher amounts of skin pigmentation, which limits cutaneous vitamin D synthesis (3), or by other genetic differences (38). Also, cultural aspects, such as wearing concealing clothes or spending less time outside, either by the mothers during pregnancy or by the children themselves, might explain these differences (39). In line with this, season was another important determinant of vitamin D status in our population. Previous studies also reported lower vitamin D concentrations in winter than in summer (14, 33, 40), and similarly, in subjects living at higher latitudes within Europe than in those living at lower latitudes (33, 40).

Important modifiable factors associated with vitamin D status are time spent outside and sedentary behavior. In our study, higher vitamin D concentrations were observed in children who played outside more often, watched less television, and spent more time biking to school. Other studies in children observed similar associations with outdoor exercise (15, 33) and television watching or computer use (11, 33).

Unfortunately we had no data available on vitamin D intake at the age of 6 y. Nevertheless, we examined whether dietary characteristics in early childhood were related to vitamin D status at the age of 6 y, showing that vitamin D intake and vitamin D supplement use were not associated with vitamin D status. Previous studies reported either no association (12, 13, 15, 40, 41) or positive associations (11, 40, 42) between dietary intake and blood concentrations of vitamin D in children. Dietary intake of vitamin D is known to have a smaller contribution to vitamin D status than cutaneous production in response to sun exposure (3). In our study, the time gap between dietary measurement and vitamin D status measurement might also explain why we did not observe an association. However, a higher overall diet quality and higher intake of margarines and cooking fats in early childhood were associated with a lower risk of vitamin D deficiency. There is evidence that dietary habits track from early to later childhood (43), and one might speculate that overall diet quality may better track into later childhood (44) than vitamin D intake specifically. In The Netherlands, dairy products usually are not fortified with vitamin D; hence, other foods, such as fish, meat, margarines, cooking fats, and infant formula, might be more important sources of vitamin D for children. This may explain the lower risk of vitamin D deficiency in relation to the intake of margarines and cooking fats in our study. Some previous studies reported that children who received infant formula had higher vitamin D concentrations than children who were breastfed (10, 14). However, in our study, neither formula intake at the age of 13 mo nor history of breastfeeding was associated with vitamin D status at the age of 6 y, which might be explained by the emphasis on vitamin D supplementation for infants in The Netherlands (45).

In line with most previous studies in children (10, 13, 15, 35), we did not observe differences in vitamin D status between boys and girls. In our population, child anthropometric factors were

TABLE 2 Associations between sociodemographic and lifestyle factors and vitamin D deficiency in children aged 6 y[1]

	Multivariable model[2]		Multivariable model after stepwise backward selection[3]	
	OR (95% CI)	*P*	OR (95% CI)	*P*
Child characteristics				
Age (y)	1.41 (1.21, 1.64)	<0.001	1.39 (1.20, 1.62)	<0.001
Sex[4]	—		—	
Ethnicity (%)				
Dutch and other Western	Reference		Reference	
Turkish and Moroccan	2.90 (2.10, 4.01)	<0.001	3.07 (2.23, 4.23)	<0.001
African	3.74 (2.79, 5.01)	<0.001	3.88 (2.86, 5.27)	<0.001
Asian	3.93 (2.75, 5.61)	<0.001	4.00 (2.85, 5.62)	<0.001
Birth weight (*z* score)	0.90 (0.82, 0.98)	0.02	0.91 (0.84, 1.00)	0.04
Breastfed[4]				
Never	—		—	
Partial ≥4 mo	—		—	
Exclusive ≥4 mo	Reference		Reference	
Amount of sunlight in the month before blood draw (h/d)	0.75 (0.71, 0.79)	<0.001	0.75 (0.71, 0.79)	<0.001
Season of blood sampling				
Winter	3.42 (2.34, 5.02)	<0.001	3.38 (2.31, 4.93)	<0.001
Spring	4.53 (3.42, 5.99)	<0.001	4.50 (3.42, 5.94)	<0.001
Summer	Reference		Reference	
Fall	1.49 (1.08, 2.06)	0.02	1.47 (1.07, 2.03)	0.02
Height (*z* score)	1.07 (0.98, 1.16)	0.15	—	
Weight status				
Underweight	2.26 (1.55, 3.28)	<0.001	2.20 (1.51, 3.21)	<0.001
Normal weight	Reference		Reference	
Overweight	1.00 (0.78, 1.29)	0.99	1.03 (0.80, 1.31)	0.84
Obese	1.37 (0.90, 2.10)	0.14	1.45 (0.97, 2.18)	0.07
Participation in sports				
No	Reference		Reference	
Yes	0.83 (0.67, 1.02)	0.07	—	
Television watching				
<2 h/d	Reference		Reference	
≥2 h/d	1.29 (1.04, 1.60)	0.02	1.32 (1.06, 1.64)	0.01
Computer use				
<1 h/d	Reference		Reference	
≥1 h/d	1.13 (0.84, 1.53)	0.41	—	
Playing outside during daytime				
<1 h/d	Reference		Reference	
≥1 h/d	0.70 (0.56, 0.88)	0.01	0.71 (0.57, 0.89)	0.01
Walking to school				
<10 min/d	Reference		Reference	
≥10 min/d	0.99 (0.80, 1.22)	0.91	—	
Biking to school				
<10 min/d	Reference		Reference	
≥10 min/d	0.65 (0.48, 0.86)	0.01	0.65 (0.49, 0.86)	0.01
Parental characteristics				
Maternal folic acid use during pregnancy				
Never	Reference		Reference	
Start in first 10 wk	0.79 (0.59, 1.06)	0.11	0.77 (0.58, 1.04)	0.09
Start periconceptional	0.57 (0.43, 0.74)	<0.001	0.55 (0.41, 0.73)	<0.001
Maternal smoking during pregnancy				
Never	Reference		Reference	
In first trimester	1.01 (0.71, 1.45)	0.94	—	
Continued	1.04 (0.77, 1.40)	0.79	—	
Maternal alcohol consumption during pregnancy				
Never	Reference		Reference	
In first trimester	1.03 (0.69, 1.53)	0.90	—	
Continued	0.94 (0.74, 1.20)	0.62	—	

(Continued)

TABLE 2 *Continued*

	Multivariable model[2]		Multivariable model after stepwise backward selection[3]	
	OR (95% CI)	*P*	OR (95% CI)	*P*
Parity (at enrollment)				
Nulliparous	Reference		Reference	
Multiparous	1.33 (1.09, 1.62)	0.01	1.33 (1.10, 1.61)	0.01
Maternal age (y)	0.95 (0.93, 0.97)	<0.001	0.95 (0.93, 0.97)	<0.001
Maternal BMI (kg/m^2)	1.03 (1.01, 1.05)	0.01	1.03 (1.01, 1.05)	0.01
Maternal educational level				
Primary	1.35 (0.82, 2.21)	0.23	—	
Secondary	0.97 (0.77, 1.21)	0.76	—	
Higher	Reference		Reference	
Household income				
<2000 euros/mo	1.46 (1.04, 2.05)	0.03	1.74 (1.34, 2.27)	<0.001
2000–3200 euros/mo	1.06 (0.83, 1.37)	0.63	1.11 (0.86, 1.44)	0.40
>3200 euros/mo	Reference		Reference	
Marital status				
Married/living together	Reference		Reference	
No partner/not living together	1.14 (0.87, 1.50)	0.34	—	
Maternal employment status				
Paid job	Reference		Reference	
No paid job	1.09 (0.87, 1.36)	0.44	—	
Paternal employment status				
Paid job	Reference		Reference	
No paid job	1.20 (0.76, 1.89)	0.42	—	
Passive smoking in household				
No	Reference		—	
Yes	1.02 (0.79, 1.32)	0.89	—	
Adjusted *R* square[5]	0.43		0.42	

[1] n = 4167. 25(OH)D, 25-hydroxyvitamin D.
[2] Values are from a logistic regression analysis that included all variables for which an effect estimate is presented in the table, and reflect the risk of vitamin D deficiency [25(OH)D <50 nmol/L] per unit increase (continuous variables) or as compared with the reference group (categorical variables).
[3] Values are from a logistic regression analysis with stepwise backward selection with $P < 0.10$ as the endpoint.
[4] $P > 0.10$ in univariable analyses and therefore not included in the multivariable model.
[5] Nagelkerke pseudo *R* square.

not strongly related to vitamin D status. Children with underweight had a higher risk of vitamin D deficiency than normal-weight children, whereas there were no significant differences for overweight or obese children. This is in contrast to previous studies that reported higher prevalences of vitamin D deficiency in obese children (11, 15, 33). The fact that we did not observe associations with obesity may be explained by the young age of our population or because the association observed in other studies may be explained by other sociodemographic and lifestyle variables for which we adjusted in our analyses.

Several parental sociodemographic and lifestyle factors were associated with child vitamin D deficiency. In line with a few previous studies, a higher risk of vitamin D deficiency was associated with a lower socioeconomic status and less health-conscious behaviors (12, 14).

The Dutch Health Council recommends vitamin D supplementation for all children younger than 4 y of age (5 μg/d until 2008 and 10 μg/d thereafter) (46). In older children, vitamin D supplementation is only recommended for those with dark skin or limited sunlight exposure. This recommendation is supported by our results. However, it might be argued that all children above age 4 y could benefit from vitamin D supplementation, given the high prevalence of vitamin D deficiency observed in our study and previous studies. Indeed, the American Academy of Pediatrics recommends a dietary vitamin D intake of 400 IU/d (10 μg/d) for all children and adolescents, and vitamin D supplementation up to the same amount in those who do not achieve this dietary intake (23). Health-care providers should be aware of the high prevalence of vitamin D

TABLE 3 Associations between dietary characteristics in early childhood and vitamin D deficiency in children aged 6 y[1]

	OR (95% CI)	*P*
Diet score	0.87 (0.78, 0.97)	0.01
Dairy and cheese intake (highest vs. lowest tertile)	0.89 (0.64, 1.22)	0.46
Fish and shellfish intake (highest vs. lowest tertile)	1.02 (0.74, 1.40)	0.92
Margarine and cooking fat intake (highest vs. lowest tertile)	0.72 (0.51, 1.00)	0.05
Infant formula intake (highest vs. lowest tertile)[2]	—	
Adequate intake of vitamin D (≥10 μg/d)		
No	Reference	
Yes	0.81 (0.59, 1.12)	0.20
Vitamin D supplementation		
No	Reference	
Yes	1.08 (0.83, 1.40)	0.58

[1] n = 1915. Values are from multivariable logistic regression analyses and reflect the risk of vitamin D deficiency [25(OH)D <50 nmol/L] per unit increase (continuous variables) or as compared with the reference group (categorical variables). Models are adjusted for the child's sex, total energy intake, age at dietary assessment, age at vitamin D measurement, sunlight in the month before blood draw, season, ethnicity, weight status, and maternal age. Dietary factors are included in separate logistic regression models. 25(OH)D, 25-hydroxyvitamin D.
[2] $P > 0.10$ in univariable analyses and therefore not included in the multivariable model.

deficiency in childhood and future studies are needed to assess whether interventions to increase vitamin D concentrations in childhood will improve health outcomes.

A strength of our study is that we measured vitamin D status in a large and ethnically diverse sample of 4167 children, with a highly sensitive and accurate method (19). We assessed circulating serum 25(OH)D concentrations, the best and most widely used indicator of vitamin D status (3, 21). A limitation of our study is the loss to follow-up for blood sampling, which was mainly due to nonconsent for venipuncture. Nonresponse analysis showed that younger children, girls, and children from mothers with a lower educational level or lower household income were more likely to have no available blood samples. Although the differences were small, they might have affected the prevalence of vitamin D deficiency in our population. For example, we observed a higher prevalence of vitamin D deficiency in older children and in children from households with a lower income. The selective loss to follow-up could therefore have resulted in an overestimation (age) or underestimation (income) of vitamin D deficiency prevalence in our sample.

An important strength of this study is its population-based cohort design from early life onward, with detailed measurements of many sociodemographic and lifestyle determinants, which were not always considered in previous studies. Unfortunately, information on some potential determinants, including amount of physical activity and time spent outside, was limited. However, we did have information on participation in sports, television watching, and playing outside as indicators for these determinants. We also lacked information on sun exposure habits (i.e., clothing, and sunscreen use) and on skin pigmentation. We used the birth countries of the parents to define and categorize ethnicity. Dietary data were available at the age of ~13 mo. Possibly, the associations between dietary vitamin D intake and vitamin D status would have been stronger if we had had dietary data at the time of the vitamin D assessment. Nevertheless, it is well known that dietary vitamin D intake is a much weaker predictor of vitamin D status than sun exposure (3).

In conclusion, in this large population-based cohort of 6-y-old children, vitamin D deficiency is highly prevalent, especially among non-Western children and in winter and spring. In addition to ethnicity and season, we identified other important modifiable (i.e., maternal BMI and folic acid use during pregnancy, and child television watching, playing outside, and biking to school) and nonmodifiable (i.e., maternal age, parity, and household income, and child age) factors associated with vitamin D status among children. Supplementation or lifestyle changes are important to prevent vitamin D deficiency in children. Future studies are needed to determine whether vitamin D deficiency during childhood may affect later health.

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