Vitamin D deficiency and associated factors in adolescent girls in Beijing[1–3]

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ABSTRACT

Background: Several locally published reports indicate a high prevalence of vitamin D deficiency among adolescents in China, but no systematic population-based survey has been conducted.

Objective: The objective was to determine the prevalence of vitamin D deficiency and to study associated factors in adolescent girls in Beijing.

Design: A cross-sectional study was conducted in a random sample of 1248 Beijing girls aged 12–14 y. Nutrient intakes, ultraviolet light exposure, anthropometric characteristics, physical activity, signs and symptoms of rickets, and plasma concentrations of 25-hydroxyvitamin D, 1,25-dihydroxyvitamin D, and calcium were measured and X-rays of the hand and wrist were taken.

Results: The prevalence of clinical vitamin D and calcium deficiency (plasma 25-hydroxyvitamin D <12.5 nmol/L, plasma calcium <2.25 mmol/L, and muscle spasm at least once per week) was 9.4% in winter. The prevalence of subclinical vitamin D deficiency (25-hydroxyvitamin D <12.5 nmol/L) was 45.2% in winter and 6.7% in summer ($P < 0.0005$). Logistic regression analysis showed that subclinical and clinical vitamin D deficiency in winter were associated with low plasma 25-hydroxyvitamin D concentrations (<12.5 nmol/L) in summer, low calcium intake ($\bar{x} \pm$ SD: 280 ± 48 compared with 440 ± 61 mg/d), and low plasma calcium concentrations (<2.25 mmol/L) in winter. The odds ratios for these associations were 3.1, 1.5, and 1.5, respectively.

Conclusions: Subclinical vitamin D deficiency was widespread among Beijing adolescent girls in winter. Low plasma 25-hydroxyvitamin D concentrations in summer, low calcium intake, and low plasma calcium concentrations in winter were the main risk factors for vitamin D deficiency in winter. *Am J Clin Nutr* 2001;74:494–500.

KEY WORDS Vitamin D deficiency, adolescent girls, China, calcium intake, vitamin D intake, sunlight exposure, 25-hydroxyvitamin D, plasma calcium

INTRODUCTION

In China in the late 1970s, vitamin D deficiency rickets was reported to have a prevalence of ≈40% in infants and young children (1); more recent locally published reports estimate the prevalence to be 5–15% in adolescents in northern and central China (2). However, no uniform standards for the diagnosis of rickets in adolescents were used in these studies, and serum or plasma 25-hydroxyvitamin D [25(OH)D)] concentrations, known to be the best indicators of vitamin D status (3, 4), were not included in the diagnostic standards.

Inadequate sunlight exposure and a low intensity of ultraviolet light in winter are suspected to be the major reasons for rickets in infants and young children in China, particularly given the higher rates in the northern parts of the country than in the south (1, 5). However, vitamin D deficiency might also occur more frequently in populations for whom the vitamin D supply is limited and whose diets are low in calcium or calcium bioavailability than in populations for whom the vitamin D supply condition is similar but dietary calcium is not low (6). No evidence for a relation between vitamin D deficiency and calcium intake in humans has been published. Additionally, no population-based data are available on vitamin D status in adolescents in Beijing and other areas in China where calcium intakes are low and the vitamin D supply is limited. The present cross-sectional study was conducted in a random sample of adolescent girls in the Beijing area from September 1995 to March 1996 to determine the prevalence of clinical vitamin D and calcium deficiency and subclinical vitamin D deficiency, to identify associated factors, and to explore the relation between calcium intake and vitamin D status.

SUBJECTS AND METHODS

Subjects

We studied girls aged 12–14 y ($\bar{x} \pm$ SD: 12.9 ± 0.5 y) who had no evidence of liver, kidney, or other disorders that may have caused nonnutritional rickets or abnormal bone development. A total of 1277 girls were randomly selected from 13 middle schools in the Beijing area (latitude 40°N) by means of a stratified, systematic, cluster-sampling procedure. Socioeconomic areas

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(urban, suburban, and rural) were defined by family income (rural or urban: low or high), adult occupation (farmers or others), location (far from or near to the city center) and infrastructure (underdeveloped or developed), with suburban in between. The acceptance rate was 94%; 76 of the 1277 subjects declined to participate in the blood tests. Forty-seven of these 76 girls completed food-frequency questionnaires, which were included in the data analysis, resulting in a total of 1248 subjects in the sample. A subsample of 649 girls (≈50 from each school) was drawn randomly from the overall project sample for measurement of biochemical variables and ultraviolet sunlight exposure in winter. A subsample of 254 girls (≈20 of the 50 girls at each school) was further randomly selected from the winter subsample for paired blood measurements in summer (September-October) and winter (January). The study received written approval from the Committee on Experimental Procedures Involving Human Subjects of the University of New South Wales, and written consent was obtained from the parents of all participants.

Nutrient intakes

A 103-item semiquantitative food-frequency questionnaire (SFFQ) was developed by means of a data-based approach (7) with use of weighed-food intake data for Beijing residents in the 1992 National Nutrition Survey (8). The food list represented 86% of the calcium intake of the population. Intakes of vitamin D, protein, and energy were also considered in determining the food list. Some foods rich in calcium, protein, and energy and observed to be popular among Beijing adolescent girls were added to the list, whereas oil that would be difficult for the girls to quantify was not included (an estimate was added later). Chinese measures (bowls and spoons, standard size) were used to quantify food items. The food-composition data were from the Chinese food tables, apart from vitamin D values, which were obtained from the UK food-composition tables (9, 10). A data entry and nutrient calculation program named CAVD (11) that uses EPI INFO (version 6; World Health Organization/Centers for Disease Control and Prevention, Atlanta) was developed together with the Information Centre at the Chinese Academy of Preventive Medicine. The girls indicated their average frequency of consumption of each food item over the past year, in specified serving sizes, by marking 1 of 10 frequency categories. The validity study of the SFFQ, conducted in a random subsample of 221 girls, showed that correlation coefficients for calcium, vitamin D, protein, energy, and phosphorus with a 6-d dietary recall (two 3-d dietary recalls spaced 6 mo apart for seasonal differences) were 0.62, 0.75, 0.53, 0.39, and 0.50, respectively. Actual food and nutrient intakes were obtained by adjusting the results from SFFQ against those from the 6-d dietary recall by means of regression equations. Fat intake was further adjusted by adding 22.4 g oil/d (the average intake of a Chinese adult in 1992) to each subject's reported intake (12). The SFFQs were self-administered at school by the subjects, with the assistance of a set of food measure models, under the supervision of the chief investigator.

Ultraviolet light exposure

A semiquantitative personal ultraviolet light dosimeter (John Thatcher & Associates Pty Ltd, Hong Kong, China) that was validated by the Australian Photobiology Testing Facility at the University of Sydney (G Murphy, unpublished observations, 1995) was used to measure ultraviolet light exposure from sunlight (13, 14). The dosimeter uses a photoreactant that absorbs UVB (ultraviolet B waveband: 280–320 nm, required for effective production of vitamin D in skin) and changes color in proportion to light intensity. The badge was attached to the top of the shoulder, outside of the clothes, for a whole day. Five badges were used for 5 consecutive days (3 weekdays and 2 weekend days) to obtain an average daily exposure dose of UVB (in mJ/cm^2) with use of a reference series of hues for each subject. The major use of the badge in this study, however, was for comparison of ultraviolet light exposure between individuals, between groups, and between seasons, and to estimate outdoor activity time, not for calculating absolute values of ultraviolet light exposure. The measurements were made in early October 1995 for summer exposure and in mid-January 1996 for winter exposure, immediately after blood sample collection.

Biochemical measurements

Plasma 25(OH)D and 1,25-dihydroxyvitamin D [$1,25(OH)_2D$] were measured in overnight fasting blood samples by means of modified competitive-protein-binding assays (15, 16). Three quality control samples of low, medium, and high concentrations were analyzed in each assay. Inter- and intraassay CVs were 12.5% and 5%, respectively, for 25(OH)D and 22% and 6.9%, respectively, for $1,25(OH)_2D$. Plasma calcium was measured by atomic absorption spectroscopy (SPECTR AA20; Varian, Sydney, Australia). Inter- and intraassay CVs for plasma calcium analyses were 4.08% and 3.81%, respectively. Summer-winter paired samples were tested in the same run to exclude interassay variance.

Medical and radiologic examinations

Symptoms and signs of rickets, including bow leg (distance between knees ≥3 cm when standing straight with ankles touching), knock-knee (distance between ankles ≥3 cm when standing straight with knees touching) (17), enlarged wrist, costochondral beading, pigeon chest, leg and joint pain (occurring while at rest especially while asleep), and muscle spasm (at least once per week) in the legs or toes, were recorded. X-rays of the nondominant hand and wrist were taken with use of a portable X-ray machine in winter (January) by technicians from the Beijing Anthropometry Centre. The X-rays were assessed for signs of rickets by a radiologist not associated with this study.

Other measurements

Other measurements included body weight, measured by using calibrated scales (RGT-140; No. 6 Machinery Plant, Beijing) while subjects wore only light clothes and no shoes; height, measured by using body height measures (TG-III; No. 6 Machinery Plant); and physical activity, estimated by using the school physical activity score (range: 1–4, where 1 = most active and best performance) awarded by schoolteachers once per semester. The subjects entered their scores into the questionnaire and the scores were double-checked with the teachers. Bone mineral measurements will be reported separately.

Diagnostic criteria

Vitamin D deficiency rickets was defined as clinical signs and symptoms of rickets, plasma 25(OH)D concentrations <12.5 nmol/L, and X-ray signs of rickets. Clinical vitamin D and calcium deficiency was defined as muscle spasm in the legs or toes at least once per week, plasma 25(OH)D concentrations <12.5 nmol/L, and plasma Ca concentrations <2.25 mmol/L. Subclinical vitamin D deficiency was defined as plasma 25(OH)D

TABLE 1
Physical characteristics of adolescent girls in the Beijing area in 1995[1]

	Rural	Suburban	Urban
Age (y)	13.2 ± 0.6[2,3]	13.0 ± 0.6[3]	12.7 ± 0.4
Height (cm)	153.8 ± 5.6	154.6 ± 5.7	154.2 ± 6.6
Weight (kg)	45.2 ± 8.0[3]	46.1 ± 8.8	46.8 ± 10.2
BMI (kg/m^2)	19.0 ± 2.9[3]	19.2 ± 3.1	19.6 ± 3.8
SPAS	1.8 ± 0.8[2]	2.1 ± 0.8	1.8 ± 0.8[2]

[1] $\bar{x}$ ± SD; n = 1248. SPAS, school physical activity score (score: 1–4, where 1 = most active and best performance).
[2] Significantly different from suburban, $P < 0.05$ (ANOVA, Tukey's test).
[3] Significantly different from urban, $P < 0.05$ (ANOVA, Tukey's test).

concentrations <12.5 nmol/L (2, 16, 18–24). 25(OH)D concentrations <12.5 nmol/L were used as an indication of vitamin D deficiency as recommended by several authorities and researchers, and because 15.2 nmol/L was reported by Xue et al (18) as the low limit of 25(OH)D concentrations of healthy children and young adults aged 7–20 y in Beijing ($\bar{x}$ ± SD: 47.8 ± 16.3 nmol/L for winter and spring). Muscle spasm was used as the only clinical symptom in the clinical vitamin D and calcium deficiency diagnosis because it is a typical clinical symptom of hypocalcemia, which is common in vitamin D deficiency (19, 25, 26), and it was one of few frequently reported symptoms by Chinese girls with osteomalacia (2).

Statistical analyses

Descriptive statistics were computed for all variables by socioeconomic area. Repeated-measures analysis of variance with the general linear models procedure was used for winter-summer paired indexes to report effects of season, area, and interaction of season and area. Post hoc multiple comparisons were made by using Tukey's test. The prevalences of clinical vitamin D and calcium deficiency and of subclinical vitamin D deficiency were calculated. Logistic regression analysis was performed to determine the role of season, area, and season × area on subclinical vitamin D deficiency. Furthermore, variables that were found to be significantly correlated with winter vitamin D deficiency, including clinical vitamin D and calcium deficiency and subclinical vitamin D deficiency, were analyzed by logistic regression to identify the predictors or determinants and to estimate relative risk. In the logistic regression analysis, continuous variables were converted into dichotomous variables by the cutoff denoting deficiency [for plasma 25(OH)D and calcium] or by the median denoting high and low intakes (for calcium and vitamin D intakes). Predictors of vitamin D deficiency in summer were also analyzed. All data were analyzed by using SPSS for WINDOWS (release 10.0; SPSS Inc, Chicago).

RESULTS

The physical characteristics of the sample are shown in **Table 1**. Compared with urban girls, rural girls were slightly older and weighed less.

Nutrient intake and vitamin D supply

The calcium, vitamin D, protein, phosphorus, and energy intakes of the subjects are shown in **Table 2**. The average intakes of dietary calcium and vitamin D were 360 mg/d and 1.05 μg/d, respectively. Protein intake was also low at 50 g/d. About 60% of the calcium intake was from plant foods, whereas only 40% was from animal foods. About 20% of calcium was from milk and milk products, including fresh milk, powdered milk, vitamin D–fortified milk and yogurt. The average consumption of milk and milk products for 66% of the girls was 97 g/d; the remaining 34% of the girls (mainly in the rural area) consumed no milk products. Dietary vitamin D was derived mainly from eggs (52.6%) and milk (35.4%), and from cakes and pastries (11.4%), which are traditionally made with egg.

Doses of ultraviolet light were significantly lower in winter than in summer ($P < 0.0005$). Rural and suburban girls had higher ultraviolet light exposures across the seasons than did urban girls (**Table 3**).

Prevalence of vitamin D and calcium deficiency

There was no radiologic evidence of active rickets among the girls. Bow legs observed in 19.4% of the girls and other bone deformities such as pigeon chest (2.5%), costochondral beading (3.0%), knock-knee (0.2%), and enlarged wrist (0.2%) were probably sequelae of rickets in early childhood.

The distribution of plasma 25(OH)D concentrations by season is shown in **Figure 1**. Plasma 25(OH)D ranged from 3 to 62 nmol/L ($\bar{x}$ ± SD: 13.4 ± 7.5 nmol/L) in winter and from 6 to 69 nmol/L (27.1 ± 11.1 nmol/L) in summer.

Average plasma concentrations of 25(OH)D, calcium, and 1,25$(OH)_2$D for subjects with paired data are shown in **Table 4**. Seasonal differences in each of these 3 indexes were significant. For 25(OH)D and calcium, winter values were lower than summer values ($P < 0.0005$). These values also varied by area: urban

TABLE 2
Nutrient intakes of girls aged 12–14 y in the Beijing area in 1995[1]

Nutrient intake	Rural	Suburban	Urban	Chinese RDA[2]	Chinese Percentage of RDA
					%
Calcium (mg/d)	318 ± 94[3,4]	352 ± 87[4]	396 ± 91	1200	30
Vitamin D (μg/d)	0.59 ± 0.65[3,4]	0.75 ± 0.62[4]	1.55 ± 1.03	10	10.5
Phosphorus (mg/d)	705 ± 119[3,4]	736 ± 106[4]	764 ± 107	—	—
Protein (g/d)	47 ± 9[3,4]	51 ± 8	52 ± 8	80	62.5
Energy (kJ/d)	6962 ± 768	7003 ± 648	7021 ± 669	9628	72.7

[1] $\bar{x}$ ± SD; n = 1248.
[2] Chinese recommended daily allowance for females aged 13–15 y and weighing 42.4 kg (27).
[3] Significantly different from suburban, $P < 0.05$ (ANOVA, Tukey's test).
[4] Significantly different from urban, $P < 0.05$ (ANOVA, Tukey's test).

TABLE 3
Ultraviolet sunlight exposure of girls aged 12–14 y in the Beijing area in 1995–1996[1]

Ultraviolet light dose	Rural (n = 24)	Suburban (n = 35)	Urban (n = 75)
Winter (mJ/cm² UVB)[2,3]	34.2 ± 11.4[a]	15.9 ± 4.1[b]	14.9 ± 5.1[c]
Summer (mJ/cm² UVB)[3]	59.8 ± 13.5[a]	43.3 ± 22.3[b]	36.0 ± 11.4[c]

[1] $\bar{x}$ ± SD. UVB, ultraviolet B waveband (≈280–320 nm). Means within a row with different superscript letters are significantly different, P < 0.05 (Tukey's test).
[2] Significant main effect of season, P < 0.0005 (repeated-measures ANOVA).
[3] Significant main effect of area, P < 0.0005 (repeated-measures ANOVA).

girls had higher plasma 25(OH)D and lower plasma calcium concentrations than did rural girls in both seasons. For 1,25$(OH)_2$D, there was a season × area interaction: winter 1,25$(OH)_2$D concentrations were higher in rural and suburban areas [a reverse trend to 25(OH)D and calcium], but not in urban areas. No significant correlations were found between these indexes. The rates of elevated 1,25$(OH)_2$D concentrations (reference range in this laboratory: 46–207 pmol/L) were 46.9% in winter and 35.4% in summer (McNemar test, P = 0.05).

In winter, the prevalence of clinical calcium and vitamin D deficiency was 9.4% and that of subclinical vitamin D deficiency was 45.2%. Vitamin D deficiency was less frequent summer, with a prevalence of subclinical vitamin D deficiency of only 6.7% (**Table 5**). Season was the only predictor of subclinical vitamin D deficiency (P < 0.0005). The risk of subclinical vitamin D deficiency was 10.5 times higher in winter than in summer (odds ratio: 11.5, 95% CI: 6.8, 19.4). There were no significant differences in subclinical vitamin D deficiency or in clinical calcium and vitamin D deficiency by area. The same conclusion about effects of season, area, and season × area on subclinical vitamin D deficiency was reached by logistic regression analyses with winter-summer paired data only, with single winter or summer data only (the winter value was removed if a subject had both winter and summer values), and with all data together. Thus, the data presented here are all those available, including 212 paired data sets.

Factors associated with vitamin D deficiency in logistic regression models

Three of 4 variables having a significant correlation with the dependent variable, vitamin D deficiency in winter, ie, plasma 25(OH)D concentrations in summer, plasma calcium concentrations in winter, and calcium intake, were shown to be predictors of vitamin D deficiency (**Table 6**). Vitamin D intake in dichotomous form (divided by the median of 0.75 μg/d: 0.34 ± 0.22 compared with 1.76 ± 0.86 μg/d) did not meet the selection criteria and was therefore not included in the model. In the logistic model, when plasma 25(OH)D concentrations in summer were <12.5 nmol/L, the risk of vitamin D deficiency in winter was triple that when plasma 25(OH)D concentrations in summer were ≥12.5 nmol/L (odds ratio: 3.1). Compared with an average calcium intake of 440 ± 61 mg/d (range: 356–647 mg/d), an intake of 280 ± 48 mg/d (range: 169–355 mg/d) was associated with a 50% higher risk of vitamin D deficiency (odds ratio: 1.5). Similarly, the risk of vitamin D deficiency in winter was 50% higher when plasma calcium concentrations in winter were <2.25 mmol/L than when they were ≥2.25 mmol/L. For the probability of vitamin D deficiency in summer, low plasma 25(OH)D concentrations in winter (<12.5 nmol/L) and low plasma calcium concentrations in summer (<2.25 nmol/L) were predictors, with odds ratios of 3.4 (95% CI: 1.2, 9.5) and 2.1 (95% CI: 1.0, 4.3), respectively.

DISCUSSION

No vitamin D deficiency rickets was diagnosed in this randomly selected sample of Beijing adolescent girls. This result differs markedly from previous reports of the prevalence of late rickets (5–15%) in Chinese adolescents. We suggest 3 reasons for this discrepancy. First, some of the previous surveys were conducted among subjects living at more northerly latitudes or in regions where the skies are overcast most of the year. Second, the diagnostic criteria and quality controls used in the other reports may have been less specific than those used by us. Third, none of the previously published studies were based on subjects sampled on a population basis. Nevertheless, clinical vitamin D and calcium deficiency, defined by plasma 25(OH)D and calcium concentrations less than the cutoffs and spasms in the legs or toes at least once per week, was observed in 9.4% of the girls in the present study in winter.

The vitamin D status of these Beijing adolescent girls should be regarded as low because of the high prevalence of subclinical vitamin D deficiency in winter (45.2%), which together with clinical vitamin D and calcium deficiency affected 54.6% of the girls. This prevalence is higher than the 6–44% reported in the 1980s for plasma 25(OH)D <12.5 nmol/L among Asian children and adolescents in the United Kingdom (19, 28), and is also higher than the 31% <30 nmol/L reported in Spanish children at a latitude of 43°N and the 34% <15 nmol/L in French white adolescents (29, 30). Prevalences of subclinical vitamin D deficiency

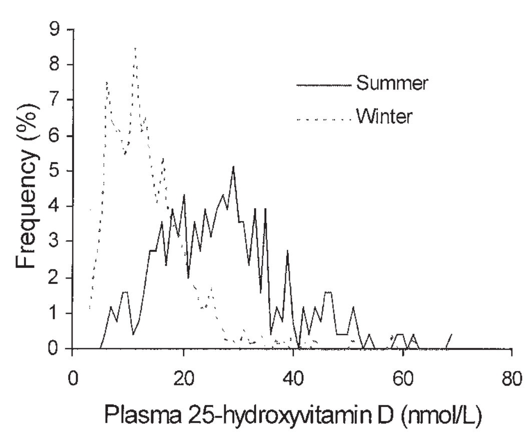

FIGURE 1. Distribution of plasma 25-hydroxyvitamin D concentrations in girls aged 12–14 y in winter (n = 603) and summer (n = 254) in the Beijing area (latitude 40°N).

TABLE 4
Biochemical indexes of girls aged 12–14 y in the Beijing area[1]

Plasma index	Rural	Suburban	Urban
25(OH)D (nmol/L)[2–4]			
Winter	12.8 ± 6.7[a] [64]	12.7 ± 5.9 [57]	13.9 ± 9.6[b] [108]
Summer	23.8 ± 8.7[a] [64]	24.7 ± 10.6 [57]	30.2 ± 11.9[b] [108]
Calcium (mmol/L)[2,5]			
Winter	2.31 ± 0.07[b] [60]	2.37 ± 0.08[c] [55]	2.26 ± 0.12[a] [96]
Summer	2.39 ± 0.08[b] [60]	2.43 ± 0.08[c] [55]	2.34 ± 0.09[a] [96]
1,25(OH)$_2$D (pmol/L)[6,7]			
Winter	217 ± 50 [25]	231 ± 51 [18]	191 ± 51 [54]
Summer	196 ± 35 [25]	203 ± 46 [18]	200 ± 74 [54]

[1] $\bar{x}$ ± SD; number of subjects for whom paired data were available in brackets. 25(OH)D, 25-hydroxyvitamin D; 1,25(OH)$_2$D, 1,25-dihydroxyvitamin D. Means within a row with different superscript letters are significantly different, $P < 0.05$ (Tukey's test).
[2,6] Significant main effect of season (repeated-measures ANOVA): [2] $P < 0.0005$, [6] $P < 0.05$.
[3,5] Significant main effect of area (repeated-measures ANOVA): [3] $P < 0.01$, [5] $P < 0.0005$.
[4,7] Significant season × area interaction (repeated-measures ANOVA): [4] $P < 0.0005$, [7] $P < 0.05$.

as assessed by plasma 25(OH)D concentrations have not been previously reported in Chinese children. In a study of the vitamin D status of 150 Hong Kong infants aged 18 mo, serum 25(OH)D concentrations were normal (≥25 nmol/L) (31). Specker et al (32) found that of 256 term Chinese infants, 57% had cord serum 25(OH)D concentrations <27.5 nmol/L. Additionally, mean 25(OH)D concentrations of the infants in the north of the country were lower than those in the south (32). There is little doubt that inadequate vitamin D supply from sunlight was a major cause of subclinical vitamin D deficiency in the Beijing girls because the prevalence of vitamin D deficiency was much higher in winter than in summer.

The findings that plasma 25(OH)D concentrations in winter were positively associated with plasma 25(OH)D concentrations in summer, that no relation existed between plasma 25(OH)D concentrations in winter and ultraviolet light exposure, and that plasma 25(OH)D concentrations ≥12.5 nmol/L in summer were associated with a two-thirds lower risk of vitamin D deficiency in winter all suggest that little vitamin D was formed in the skin of these girls in winter. We also conclude that because dietary vitamin D intake was only ≈1 μg/d, vitamin D formed in the skin in summer was the most important determinant of vitamin D status in winter. Therefore, children with plasma 25(OH)D concentrations <12.5 nmol/L in summer were more likely to have vitamin D deficiency in winter. Longer exposure to sunlight in summer among children should be encouraged. This observation of an association between summer and winter plasma 25(OH)D concentrations has not previously been reported in a population study, although seasonal fluctuations in 25(OH)D concentrations are well documented in healthy adults and children in northern latitudes in Europe and North America (29, 30, 33–36).

Our results support those of Holick et al (37), who found no significant production of vitamin D_3 in the skin during winter months in Boston (latitude 42°N). The absolute values of ultraviolet light exposure in Table 3 should be interpreted with caution, however, because the dosimeter we used tends to overestimate rather than underestimate the ultraviolet light dose to human skin from natural sunlight. Although it has been well documented that 25(OH)D concentrations are related to sunlight exposure in adults and the elderly, few reports in children are available. Ho et al (38) reported that 25(OH)D concentrations increased significantly by 43% in an experimental group of 18 infants who were exposed to ≈2 h of sunshine daily for 2 mo in September through October in Beijing, whereas 25(OH)D concentrations were unchanged at the end of the period in the control group, who was exposed to 1 h of sunshine daily. Another study showed that serum 25(OH)D concentrations were significantly related to ultraviolet light exposure as monitored with a 7-d clothing and sunshine diary in infants in Cincinnati (39).

Although we found that ultraviolet light exposure in summer was double that in winter [which is consistent with our observation of 25(OH)D concentrations being twice as high in summer as in winter], we found no correlation between ultraviolet light exposure and plasma 25(OH)D concentrations in summer. This

TABLE 5
Prevalence of vitamin D and calcium deficiencies among girls aged 12–14 y in the Beijing area in 1995–1996[1]

Area	Winter (n = 533): Clinical vitamin D and calcium deficiency	Winter (n = 533): Subclinical vitamin D deficiency[3]	Summer (n = 254)[2]: subclinical vitamin D deficiency
	%	%	%
Rural	6.9 (3.1, 10.7)	45.1 (37.7, 52.5)	9.2 (2.7, 15.7)
Suburban	9.5 (4.6, 14.4)	49.6 (41.2, 58.0)	6.6 (0.4, 12.8)
Urban	11.3 (7.1, 15.5)	42.5 (36.0, 49.0)	5.1 (1.1, 9.1)
Total	9.4 (6.9, 11.9)	45.2 (41.0, 49.4)	6.7 (3.6, 9.8)

[1] 95% CI in parentheses. Data presented are all those available, including 212 sets of paired data.
[2] The prevalence of clinical vitamin D and calcium deficiency was not available for summer.
[3] In the logistic regression of subclinical vitamin D deficiency (forward stepwise method), season was a predictor [$P < 0.0005$; odds ratio: 11.5 (winter compared with summer); 95% CI: 6.8, 19.4].

TABLE 6
Logistic regression models for probability of vitamin D deficiency of girls aged 12–14 y in the Beijing area in winter[1]

	β	SE	*P*	Odds ratio (95% CI)
Summer plasma 25(OH)D (nmol/L)	1.1314	0.5336	0.034	3.1 (1.1, 8.8)
Winter plasma calcium (mmol/L)	0.4249	0.1636	0.009	1.5 (1.1, 2.1)
Calcium intake (mg/d)	0.3996	0.1472	0.007	1.5 (1.1, 2.0)
Constant	−1.4191	0.5378	0.007	—

[1] n = 207. Forward stepwise (likelihood ratio) method; entry criteria = $P < 0.05$. The overall percentage of correct prediction was 65.1%. Subjects who had blood tested in both winter and summer were included in the analysis. β, standard regression coefficient; 25(OH)D, 25-hydroxyvitamin D.

contrasts with the results of a study by Brock et al (40) in an elderly Sydney population in which the same ultraviolet light dosimeter and method were used. Our subjects were more active than the elderly Sydney population, however, and 5 d of ultraviolet light monitoring may not have been long enough to obtain usual ultraviolet light exposure; a clothing diary should also have been included. In addition, calcium and vitamin D intakes might influence the relation between ultraviolet light exposure and plasma 25(OH)D concentrations. For example, rural girls, who had lower plasma 25(OH)D concentrations in summer (Tables 2–4) than did urban girls, had higher ultraviolet light exposure but lower calcium and vitamin D intakes. An influence of calcium and vitamin D intakes is also supported by an improvement, although not significant, in the correlation coefficients between ultraviolet light exposure and plasma 25(OH)D after control for vitamin D and calcium intakes.

The logistic regression analysis showed that risk of vitamin D deficiency in winter was ≈50% higher when calcium intakes were below rather than above the median. No such relation was observed in summer. This appears to be the first report of a previously postulated (6) association between vitamin D deficiency and low calcium intake combined with low vitamin D supplies in humans. The mechanism by which low calcium intake contributed to the high prevalence of vitamin D deficiency among Beijing girls in winter cannot be discerned from the present study; however, our findings do suggest that where there is a low supply of both vitamin D and calcium, both factors contribute to the etiology of vitamin D deficiency and both deficiencies should be corrected to prevent vitamin D deficiency in such populations.

Actual vitamin D intake was probably lower than what is shown in Table 2. A recent sampling of eggs and cakes from a local Beijing market showed the vitamin D contents of these foods to be lower than the values listed in the UK food tables, probably because of a difference in the vitamin D content of chicken feed (Q Zhang, unpublished observations, 2000). Vitamin D–fortified milk (containing 600 IU vitamin D/L, or 15 μg/L), the other major source of dietary vitamin D for these girls, has been available in Beijing since 1989. However, the actual content of vitamin D in the milk samples was also lower than that labeled (Q Zhang, unpublished observations, 2000).

The results of this study suggest that Beijing girls aged 12–14 y should consume ≥600 mg Ca and 5 μg vitamin D (in winter) daily. This amount of calcium is based on the higher calcium intake of the Beijing girls sampled, which was associated with a 50% increase in protection from vitamin D deficiency ($\bar{x}$ + 2 SD: 440 + 2 × 61 mg/d). The vitamin D value is based on the current intake of the girls with plasma 25(OH)D concentrations ≥12.5 nmol/L in winter ($\bar{x}$ + 2 SD: 1.2 + 2 × 1.08 μg/d), the maximum dietary vitamin D intake in the vitamin D deficiency group (4.2 μg/d), and the current ultraviolet light exposure of the girls.

In summary, our results from a representative sample of Beijing adolescent girls show for the first time the moderate prevalence of clinical vitamin D and calcium deficiency (9.4%) and the high prevalence of subclinical vitamin D deficiency (45.2%) in winter in this population. Low plasma 25(OH)D concentrations in summer (<12.5 nmol/L) were associated with a 2.1 times higher risk of vitamin D deficiency in winter. In addition, low calcium intake (<355 mg/d, averaging 280 mg/d, compared with ≥355 mg/d, averaging 440 mg/d) was associated with a 50% higher risk of vitamin D deficiency. A comprehensive program to prevent vitamin D deficiency in Chinese children and adolescents is strongly suggested. Strategies may include improved judicious exposure to sunlight, improved dietary supplies of highly bioavailable calcium (eg, milk) and vitamin D from food fortification, and the integration of the topic of vitamin D deficiency into school physical examinations and the health education syllabus.

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