Public Health Nutrition: 17(1), 122–130 doi:10.1017/S1368980012004703

Prevalence of 25-hydroxyvitamin D deficiency in Korean adolescents: association with age, season and parental vitamin D status

Shin Hye Kim[1], Min Kyung Oh[2], Ran Namgung[3,*] and Mi Jung Park[1,*]
[1]Department of Pediatrics, Sanggye Paik Hospital, Inje University College of Medicine, 761-1 Sanggye-7-dong, Nowon-gu, Seoul 139-707, Republic of Korea: [2]Clinical Trial Center, Busan Paik Hospital, Inje University College of Medicine, Busan, Republic of Korea: [3]Department of Pediatrics, Yonsei University College of Medicine, 50 Yonsei-ro, Seodaemung-gu, Seoul 120-752, Republic of Korea

Submitted 9 April 2012: Final revision received 10 August 2012: Accepted 24 August 2012: First published online 26 October 2012

Abstract

Objective: We aimed to assess the prevalence and associated factors of vitamin D deficiency in healthy adolescents and to determine parent–adolescent association in vitamin D status.
Design: A cross-sectional study.
Setting: Data from the Korean National Health and Nutrition Examination Survey (KNHANES) 2008–2009. Serum 25-hydroxyvitamin D (25(OH)D) levels were measured using ^{125}I-labelled RIA kits. Vitamin D deficiency in adolescents was defined as 25(OH)D level <27·5 nmol/l, and 25(OH)D levels between 27·5 and <50 nmol/l were considered insufficient. For the parents, vitamin D deficiency was defined as 25(OH)D level <50 nmol/l.
Subjects: The study population consisted of 2062 adolescents (1095 boys, 967 girls; aged 10–18 years) and their parents (1005 fathers, 1341 mothers).
Results: Overall, 13·4 % of adolescents (boys 11·7 %, girls 15·4 %) were 25(OH)D deficient, 54·7 % were 25(OH)D insufficient. Prevalence of vitamin D deficiency increased with age ($P < 0·0001$). Parental vitamin D deficiency was more prevalent in vitamin D-deficient adolescents than in non-deficient adolescents (all $P < 0·0001$). In multivariate logistic regression analyses, predictors for vitamin D deficiency were senior high school students (OR = 3·45–4·33), winter/spring season (OR = 3·18–5·11/5·35–7·36) and parental vitamin D deficiency (OR = 1·78–4·88; all $P < 0·05$).
Conclusions: Vitamin D insufficiency is prevalent among healthy Korean adolescents and the parent–offspring association warrants vitamin D screening for family members of deficient individuals.

Keywords
Adolescents
Vitamin D deficiency

Vitamin D is an important regulator for Ca absorption and bone growth(1). Since childhood to adolescence is a critical period for bone accretion and growth, low vitamin D status in this period is associated with numerous negative skeletal consequences, including rickets, osteomalacia, secondary hyperparathyroidism and fracture risk(2,3). In addition to skeletal effects, vitamin D insufficiency has been implicated as a risk factor for type 1 diabetes mellitus, multiple sclerosis, autoimmune conditions, CVD and cancer(4,5). Despite growing concerns over the importance of vitamin D, there are few studies that have evaluated the prevalence of 25-hydroxyvitamin D (25(OH)D) deficiency in paediatric populations on the basis of nationwide survey data(6–8). Recent studies reported that 9 % of US children(6) and 31 % of New Zealand children(7) had 25(OH)D levels <37·5 nmol/l, and 36 % of Indian adolescents had 25(OH)D levels <22·5 nmol/l(8).

Korean adolescents theoretically are at increased risk for vitamin D insufficiency because of the high latitude (34–38°N), increased use of sunscreen, reduced outdoor activity and lack of vitamin D-fortified foods. However, there has been no previous large-scale study examining the prevalence and risk factors of vitamin D deficiency in Korean adolescents. Regarding the familial association of vitamin D status, the parent–adolescent association in vitamin D status and its significance as an independent predictor for vitamin D deficiency in adolescents have also not been investigated.

The objective of the present study was to assess the prevalence and risk factors of vitamin D deficiency in healthy adolescents and to explore the relationship between vitamin D deficiency in adolescents and parental vitamin D status.

*Corresponding authors: Email ranng@yuhs.ac (Ran Namgung), PMJ@paik.ac.kr (Mi Jung Park)

Experimental methods

Study participants

Data for the present cross-sectional analysis were obtained from the Korean National Health and Nutrition Examination Survey (KNHANES) conducted from February 2008 to December 2009. This survey is a community-based cross-sectional survey that has been conducted by the Division of Chronic Disease Surveillance, Korea Centers for Disease Control and Prevention to assess the health and nutrition of a large representative sample of non-institutionalized civilians in South Korea. A stratified multi-stage probability sampling design was used for the selection of household units. In the KNHANES 2008–2009, there were 264 186 primary sampling units, each of which contained sixty households. Two hundred sampling frames from primary sampling units were randomly sampled and twenty-three households from each sampling frame were sampled using a systemic sampling method in 2008 and 2009, respectively. Finally, 12 528 individuals in 2008 and 12 722 in 2009 were sampled, and 9308 individuals in 2008 and 10 533 in 2009 participated in the survey. There were 2121 adolescents aged 10–18 years and 2469 parents among those who participated in the survey between February 2008 and December 2009. We excluded individuals who did not have adequate blood samples for measurement of 25(OH)D level (*n* 111) and those with a history of seizure disorder (*n* 4), diabetes (*n* 15), chronic liver disease (*n* 42) or kidney disease (*n* 10). The final sample for the cross-sectional analysis comprised a total of 2062 adolescents aged 10–18 years (1095 boys, 967 girls) and their parents (*n* 2346; 1005 fathers, 1341 mothers). The study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects were ethically approved by the Institutional Review Board at Inje University College of Medicine. All participants in this survey signed an informed consent form.

Data collection and study variables

The KNHANES consists of four parts: (i) a health interview survey; (ii) a health behaviour survey; (iii) a health examination survey; and (iv) a nutrition survey. Data were collected via household interviews, followed by standardized physical examinations performed by trained medical staff and collection of blood samples at a mobile examination centre.

Demographic variables include age, gender and region. Age was categorized as elementary school (age 10–12 years), junior high school (age 13–15 years) and senior high school (age 16–18 years). Among the sixteen districts of South Korea, eight major cities (Seoul, Gyeonggi, Busan, Daegu, Incheon, Gwangju, Daejeoun and Ulsan) were grouped as urban areas, and the other provinces (Gangwon, Chungbuk, Chungnam, Jeonbuk, Jeonnam, Gyeongbuk, Gyeongnam and Jeju) were grouped as rural areas.

Overweight and obesity were categorized according to the age- and sex-specific percentiles for BMI of national reference standards[9]. Overweight was defined as BMI ≥ 85th percentile and <95th percentile, and obesity was defined as BMI ≥ 95th percentile.

Assessment of participants' daily dietary Ca intake was done through a 24 h recall interview. The amount of daily Ca intake was calculated as a percentage of the Recommended Nutrient Intake (RNI) for Koreans[10]. Ca intake was categorized as sufficient when daily Ca intake of the participant was equal to or greater than the RNI. The RNI for Ca is 800 mg/d, 1000 mg/d and 900 mg/d for boys aged 10–11 years, 12–14 years and 15–18 years, respectively; the corresponding values for girls are 800 mg/d, 900 mg/d and 800 mg/d[10].

Physical activity was measured by self-report using the International Physical Activity Questionnaire[11]. Moderate physical activity was categorized as 'yes' when participants engaged in moderate-intensity physical activity for more than 20 min at a time and more than 3 times/week. Moderate-intensity physical activity was defined as the physical activity that causes a slight increase in breathing or heart rate for at least 10 min, such as when carrying light loads, bicycling at a regular pace or playing doubles tennis.

Serum 25-hydroxyvitamin D measurement

Serum 25(OH)D levels were measured in overnight fasting blood samples by ^{125}I-labelled RIA kits (Diasorin, Stillwater, MN, USA) using a gamma-counter (1470 Wizard; PerkinElmer, Turku, Finland). The interassay CV were 11·7, 10·5, 8·6 and 12·5 % at 21·5, 56·7, 82·4 and 122·3 nmol/l, respectively. We assessed the prevalence of participants with serum 25(OH)D levels of <27·5 nmol/l, ≥27·5 to <50 nmol/l, ≥50 to <75 nmol/l and ≥75 nmol/l. Vitamin D deficiency in adolescents was defined as serum 25(OH)D <27·5 nmol/l[12,13], which is the widely used cut-off value for diagnosing a deficiency in adolescents. Serum 25(OH)D between 27·5 and <50 nmol/l was considered insufficient[6,12]. For the parents, vitamin D deficiency was defined as serum 25(OH)D <50 nmol/l[14,15], which is the most recently established value for diagnosing a deficiency in adults.

Statistical analysis

Statistical analyses were conducted with the SAS statistical software package version 9·1. Data were analysed using Student's *t* test, ANOVA for continuous variables and the χ^2 test for discrete variables. Pearson's correlation analysis was performed to demonstrate the relationship between adolescents' vitamin D level and parental vitamin D status. Univariate logistic regression analyses were used to evaluate the association between possible predicting factors and vitamin D deficiency. Multivariate logistic regression analyses were also used to find the independent predictors for vitamin D deficiency. All values are expressed as mean and standard deviation or as percentages. For all analyses,

P values were two-tailed and <0·05 was considered statistically significant.

Results

General characteristics and serum 25-hydroxyvitamin D concentrations of study population

General characteristics and serum 25(OH)D levels of the participants are shown in Table 1. Mean serum 25(OH)D value was 44·2 (SD 15·2) nmol/l, which was higher in boys than in girls through all four seasons (P< 0·01). The range of 25(OH)D levels was from 13·0 to 122·6 nmol/l; the 10th, 25th, 50th, 75th and 90th percentile values were 26·0, 32·4, 41·9, 53·7 and 72·4 nmol/l, respectively (data not shown). Overall, 13·4 % of adolescents were vitamin D deficient, and the prevalence of vitamin D deficiency was higher in girls than in boys (15·4 % v. 11·7 %, P = 0·015). The prevalence of vitamin D insufficiency was 52·5 % in boys and 57·2 % in girls. Only 4·8 % of boys and 2·5 % of girls had serum 25(OH)D level ≥75 nmol/l. Daily Ca intake as %RNI (P = 0·002) and the proportion of

Table 1 General characteristics and serum 25(OH)D levels of participants and their parents: adolescents aged 10–18 years, Korean National Health and Nutrition Examination Survey (KNHANES) 2008–2009

	Total (n 2062)		Boys (n 1095)		Girls (n 967)		
	Mean or %	SD	Mean or %	SD	Mean or %	SD	P value
Age* (%)							0·9613
Elementary school	35·6		35·4		35·9		
Junior high school	36·5		36·5		36·5		
Senior high school	27·9		28·1		27·6		
Season† (%)							0·4425
Winter	25·2		24·8		25·8		
Spring	22·5		22·8		22·0		
Summer	27·3		26·7		28·5		
Autumn	25·0		26·7		23·7		
Obesity level‡ (%)							0·9924
Normal weight	85·5		85·5		85·6		
Overweight	9·8		9·9		9·7		
Obese	4·7		4·6		4·7		
Region§ (%)							0·3260
Urban	66·6		67·6		65·5		
Rural	33·4		32·4		34·5		
Sufficient Ca intake‖ (%)							0·1700
No	90·8		89·9		91·8		
Yes	9·2		10·1		8·2		
Daily Ca intake¶ (%RNI)	53·8	34·7	56·8	36·6	50·8	33·7	0·0002
Moderate physical activity** (%)							<0·0001
No	49·9		42·5		58·2		
Yes	50·1		57·5		41·8		
Mean serum 25(OH)D (nmol/l)	44·2	15·2	45·9	15·7	42·4	14·7	<0·0001
Winter (nmol/l)	37·2	12·2	38·4	12·2	35·7	11·7	0·0051
Spring (nmol/l)	37·9	13·0	39·7	13·7	35·9	11·7	0·0010
Summer (nmol/l)	52·1	15·5	53·9	16·5	50·4	14·5	0·0068
Autumn (nmol/l)	48·4	14·2	49·9	14·5	46·4	13·7	0·0078
Serum 25(OH)D (%)							0·0015
<27·5 nmol/l	13·4		11·7		15·4		
≥27·5 to <50 nmol/l	54·7		52·5		57·2		
≥50 to <75 nmol/l	28·1		31·5		24·9		
≥75 nmol/l	3·8		4·8		2·5		
Paternal 25(OH)D (%)							
<50 nmol/l	53·3		54·5		52·1		0·4525
≥50 nmol/l	46.7		45·5		47·9		
Maternal 25(OH)D (%)							
<50 nmol/l	76·3		78·3		74·5		0·1071
≥50 nmol/l	23·7		21·7		25·5		

25(OH)D, 25-hydroxyvitamin D.
*All participants were grouped as elementary school (aged 10–12 years), junior high school (aged 13–15 years) and senior high school (aged 16–18 years) according to their age.
†Seasons are noted as spring (March to May), summer (June to August), autumn (September to November) and winter (December to February).
‡Obesity level was determined according to the age- and sex-specific BMI percentile[9]: normal weight (BMI < 85th percentile), overweight (BMI ≥85th percentile and < 95th percentile) and obese (BMI ≥ 95th percentile).
§Regions were grouped as rural areas (Gangwon, Chungbuk, Chungnam, Jeonbuk, Jeonnam, Gyeongbuk, Gyeongnam and Jeju) and urban areas (Seoul, Gyeonggi, Busan, Daegu, Incheon, Gwangju, Daejeon and Ulsan).
‖Sufficient Ca intake was indicated as 'yes' when daily Ca intake of the participant was equal to or greater than the Recommended Daily Allowance[10].
¶Daily Ca intake was presented as a percentage of the Recommended Nutrient Intake (%RNI) for Koreans[10].
**Moderate physical activity was indicated as 'yes' when the participant engaged in moderate-intensity physical activity for more than 20 min at a time and more than 3 times/week.

participants doing moderate physical activity ($P < 0{\cdot}0001$) were higher in boys than in girls.

Prevalence of vitamin D deficiency/insufficiency by age

Figure 1 demonstrates the prevalence of vitamin D deficiency (<27·5 nmol/l) and insufficiency (≥27·5 to <50 nmol/l), and also shows the prevalence of participants with serum 25(OH)D level of ≥50 to <75 nmol/l and ≥75 nmol/l. Prevalence of vitamin D deficiency increased gradually from elementary school to senior high school age. For boys, prevalence of vitamin D deficiency was 4·4 % in elementary school, 12·8 % in junior high school and 19·6 % in senior high school ($P < 0{\cdot}0001$); for girls, 7·8 % in elementary school, 15·6 % in junior high school and 25·4 % in senior high school ($P < 0{\cdot}0001$).

Risk factors for vitamin D deficiency

Table 2 compares the characteristics of adolescents who were vitamin D-deficient (serum 25(OH)D <27·5 nmol/l) and non-deficient (serum 25(OH)D ≥27·5 nmol/l). Higher proportions of senior high school students and winter/spring season were noted in vitamin D-deficient adolescents compared with non-deficient adolescents (all $P < 0{\cdot}0001$). In vitamin D-deficient boys, the proportion living in rural areas ($P = 0{\cdot}0067$) and the daily Ca intake as %RNI ($P = 0{\cdot}0180$) were lower than in non-deficient boys. Parental serum 25(OH)D levels were lower and parental vitamin D deficiency was also more prevalent in vitamin D-deficient adolescents than in non-deficient adolescents (all $P < 0{\cdot}0001$). A strong correlation of the adolescent's 25(OH)D level with that of the father ($r = 0{\cdot}45$, $P < 0{\cdot}0001$) and mother ($r = 0{\cdot}44$, $P < 0{\cdot}0001$) was observed (Fig. 2).

In univariate logistic regression analyses (Table 3), risk factors associated with vitamin D deficiency were senior high school students, season and parental vitamin D deficiency in both genders (all $P < 0{\cdot}0001$). Insufficient Ca intake ($P = 0{\cdot}0381$) and residence in urban areas ($P = 0{\cdot}0073$) were also risk factors for boys. In multivariate logistic regression analyses, independent predictors for vitamin D deficiency were senior high school students, spring season and paternal vitamin D deficiency for boys (all $P < 0{\cdot}05$); senior high school students, spring/winter season and maternal vitamin D deficiency for girls (all $P < 0{\cdot}05$; Fig. 3).

Discussion

In the present study, we demonstrated that low vitamin D status is highly prevalent among healthy Korean adolescents and that adolescents' vitamin D status is highly related to parental vitamin D status.

The optimal level of 25(OH)D in adults has been suggested to be ≥75 nmol/l, a level associated with maximal suppression of parathyroid hormone and reduced fracture risk(14,15). Vitamin D deficiency in adults is commonly defined as serum 25(OH)D <50 nmol/l, where parathyroid hormone levels begin to reduce in vitamin D-deficient adults who receive vitamin D_2 supplementation(14,15). In children, there is a lack of consensus on the ideal 25(OH)D level to prevent health complications; however, limited data have suggested that serum 25(OH)D ≥50 nmol/l(16) or ≥75 nmol/l(17) is needed to decrease serum parathyroid hormone level to a low plateau in children. The 2011 report of the Institute of Medicine concluded that a serum 25(OH)D level of 50 nmol/l meets the needs of 97·5 % of the population and levels ≥75 nmol/l are not consistently associated with increased benefit(18). The 75th and 90th percentile values of serum 25(OH)D were 53·7 and 72·4 nmol/l in our study participants.

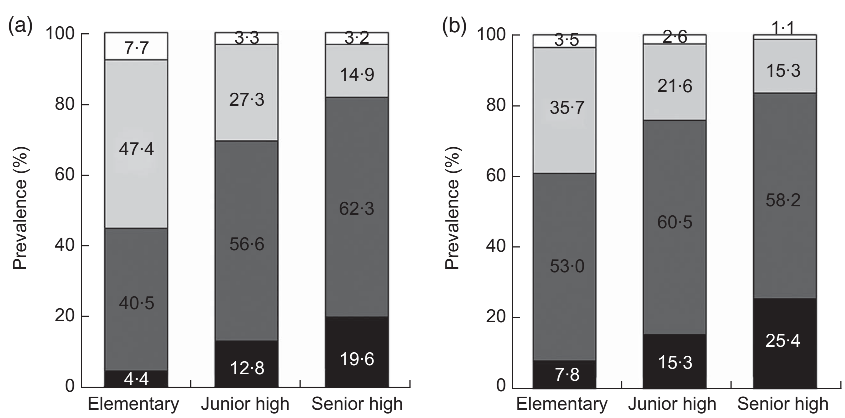

Fig. 1 Prevalence of serum 25-hydroxyvitamin D (25(OH)D) <27·5 nmol/l (■), ≥27·5 to <50 nmol/l (■), ≥50 to <70 nmol/l (□) and ≥70 nmol/l (□) by age group (elementary school, age 10–12 years; junior high school, age 13–15 years; senior high school, age 16–18 years) and sex (a, boys; b, girls): adolescents (*n* 2062; 1095 boys, 967 girls) aged 10–18 years, Korean National Health and Nutrition Examination Survey (KNHANES) 2008–2009. Prevalence of vitamin D deficiency (25(OH)D <27·5 nmol/l) increased with age in both genders ($P < 0{\cdot}0001$)

https://doi.org/10.1017/S1368980012004703 Published online by Cambridge University Press

Table 2 Comparison of participants' characteristics by sex and vitamin D status: adolescents (n 2062; 1095 boys, 967 girls) aged 10–18 years, Korean National Health and Nutrition Examination Survey (KNHANES) 2008–2009

	Boys					Girls				
	Serum 25(OH)D (nmol/l)					Serum 25(OH)D (nmol/l)				
	<27·5		≥ 27·5			<27·5		≥ 27·5		
	Mean or %	SD	Mean or %	SD	P value	Mean or %	SD	Mean or %	SD	P value
Age* (%)					<0·0001					<0·0001
Elementary school	13·3		38·4			18·1		39·1		
Junior high school	39·8		36·0			36·9		36·4		
Senior high school	46·9		25·6			45·0		24·5		
Season† (%)					<0·0001					<0·0001
Winter	40·6		22·6			42·9		22·6		
Spring	43·0		20·2			40·3		18·7		
Summer	7·0		28·8			7·4		32·4		
Autumn	9·4		28·4			9·4		26·3		
Obesity level‡ (%)					0·9835					0·1137
Normal weight	84·9		85·5			88·6		85·1		
Overweight	10·3		9·8			5·4		10·5		
Obese	4·8		4·7			6·0		4·4		
Region§ (%)					0·0067					0·1620
Urban	78·1		66·2			70·5		64·6		
Rural	21·9		33·8			29·5		35·4		
Sufficient Ca intake‖ (%)					0·0314					0·2438
No	96·9		91·1			90·6		93·3		
Yes	4·4		8·9			9·4		6·7		
Daily Ca intake¶ (%RNI)	46·8	31·0	58·4	36·3	0·0180	50·7	32·4	50·0	38·1	0·8264
Moderate physical activity** (%)					0·3799					0·0528
No	46·2		41·9			65·7		56·6		
Yes	53·8		58·1			34·3		43·3		
Paternal 25(OH)D (nmol/l)	38·7	11·2	52·4	16·5	<0·0001	43·9	14·5	55·4	18·2	<0·0001
Maternal 25(OH)D (nmol/l)	31·4	11·7	41·4	14·2	<0·0001	31·7	11·2	44·2	15·2	<0·0001
Paternal 25(OH)D (%)										
<50 nmol/l	86·1		48·9		<0·0001	74·7		46·8		<0·0001
≥50 nmol/l	13·9		51·1			25·3		53·2		
Maternal 25(OH)D (%)										
<50 nmol/l	96·2		75·1		<0·0001	93·7		70·4		<0·0001
≥50 nmol/l	3·8		24·9			6·4		29·6		

25(OH)D, 25-hydroxyvitamin D.
*All participants were grouped as elementary school (age 10–12 years), junior high school (age 13–15 years) and senior high school (age 16–18 years) according to their age.
†Seasons are noted as spring (March to May), summer (June to August), autumn (September to November) and winter (December to February).
‡Obesity level was determined according to the age- and sex-specific BMI percentile[9]: normal weight (BMI <85th percentile), overweight (BMI ≥85th percentile and <95th percentile) and obese (BMI ≥95th percentile).
§Regions were grouped as rural areas (Gangwon, Chungbuk, Chungnam, Jeonbuk, Jeonnam, Gyeongbuk, Gyeongnam and Jeju) and urban areas (Seoul, Gyeonggi, Busan, Daegu, Incheon, Gwangju, Daejeon and Ulsan).
‖Sufficient Ca intake was indicated as 'yes' when daily Ca intake of the participants was equal to or greater than the Recommended Daily Allowance[10].
¶Daily Ca intake was presented as a percentage of the Recommended Nutrient Intake (%RNI) for Koreans[10].
**Moderate physical activity was indicated as 'yes' when the participant engaged in moderate-intensity physical activity for more than 20 min at a time and more than 3 times/week.

We defined vitamin D insufficiency as serum 25(OH)D <50 nmol/l rather than <75 nmol/l, which could define the majority (96·2 %) of Korean adolescents as insufficient. The 25(OH)D cut-off value for defining deficiency in children and adolescents varies between studies, with the majority consensus setting the level at 25–30 nmol/l, based on 25(OH)D levels found in children with reduced bone mineral density or rickets[6,16,17,19]. Also, the Institute of Medicine report suggests that persons are at risk of vitamin D deficiency at serum 25(OH)D levels <30 nmol/l[20]. We defined vitamin D deficiency as serum 25(OH)D <27·5 nmol/l, which corresponds to the Institute of Medicine recommendations and the 10th percentile value of our participants' 25(OH)D levels.

We found that the mean serum 25(OH)D level of Korean adolescents (44·2 nmol/l) was lower than the reported values of 63·9 nmol/l among US adolescents[21] and 50 nmol/l among New Zealand children[7]. The prevalence of vitamin D deficiency among senior high school students (19·6–25·4 %) in Korea (34–38°N) was higher than the reported 18 % among UK (50–58°N) adolescents[22] and 10–13 % among Canadian (45–48°N) adolescents[23]. It has been well documented that vitamin D deficiency in adolescence is highly prevalent in Indian[8] (36 %), Iranian[24] (86 %), Mexican[6] (7–20 %) and non-Hispanic black[6] (43–59 %) populations, because skin pigmentation of these ethnic groups reduces the skin's production of vitamin D_3. Besides dark-skinned ethnic groups,

https://doi.org/10.1017/S1368980012004703 Published online by Cambridge University Press

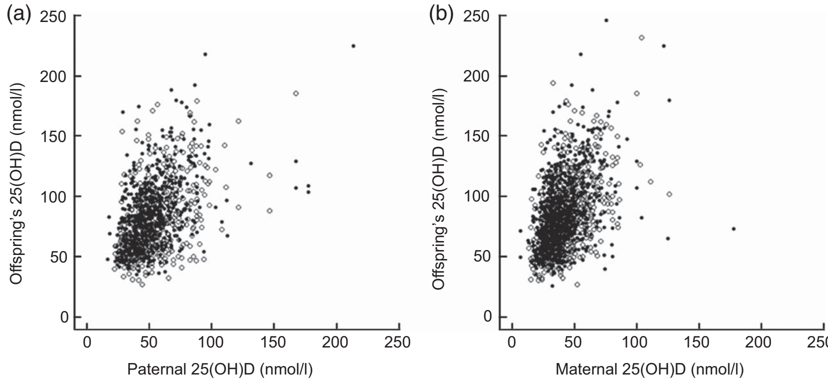

Fig. 2 Relationship between (a) offspring's 25-hydroxyvitamin D (25(OH)D) level and paternal 25(OH)D level ($r = 0·45$, $P < 0·0001$) and (b) offspring's 25(OH)D level and maternal 25(OH)D level ($r = 0·44$, $P < 0·0001$), by sex (●, boys; ○, girls): adolescents (*n* 2062; 1095 boys, 967 girls) aged 10–18 years, Korean National Health and Nutrition Examination Survey (KNHANES) 2008–2009

Table 3 Univariate logistic regression models for probability of vitamin D deficiency in participants: adolescents (*n* 2062; 1095 boys, 967 girls) aged 10–18 years, Korean National Health and Nutrition Examination Survey (KNHANES) 2008–2009

	Boys			Girls		
	OR	95 % CI	*P* value	OR	95 % CI	*P* value
Age*						
Elementary school	–	–		–	–	
Junior high school	3·20	1·81, 5·64	0·1110	2·19	1·34, 3·56	0·6257
Senior high school	5·28	3·01, 9·26	<0·0001	3·97	2·46, 6·41	<0·0001
Season†						
Winter	7·33	3·54, 15·21	<0·0001	8·33	4·28, 16·23	<0·0001
Spring	8·71	4·20, 18·04	<0·0001	9·45	4·82, 18·52	<0·0001
Summer	–	–	–	–	–	–
Autumn	1·35	0·56, 3·25	0·0008	1·57	0·70, 3·53	0·0009
Obesity level‡						
Normal weight	–	–		–	–	
Obese	1·03	0·43, 2·42	0·9975	1·32	0·62, 2·80	0·1314
Region§						
Rural	–	–		–	–	
Urban	1·82	1·18, 2·83	0·0073	1·31	0·90, 1·92	0·1630
Sufficient Ca intake‖						
Yes	–	–		–	–	
No	2·65	1·06, 6·68	0·0381	0·77	0·40, 1·49	0·4371
Moderate physical activity¶						
Yes	–	–		–	–	
No	1·19	0·81, 1·76	0·3803	1·47	0·994, 2·17	0·0537
Paternal 25(OH)D (nmol/l)						
<50	6·11	3·23, 11·53	<0·0001	3·37	2·01, 5·62	<0·0001
≥50	–	–		–	–	
Maternal 25(OH)D (nmol/l)						
<50	8·44	3·06, 23·30	<0·0001	6·322	2·90, 13·90	<0·0001
≥50	–	–		–	–	

25(OH)D, 25-hydroxyvitamin D.
*All participants were grouped as elementary school (age 10–12 years), junior high school (age 13–15 years) and senior high school (age 16–18 years) according to their age.
†Seasons are noted as spring (March to May), summer (June to August), autumn (September to November) and winter (December to February).
‡Obesity level was determined according to the age-and sex-specific BMI percentile[9]: normal weight (BMI <85 percentile) and obese (BMI ≥95 percentile).
§Regions were grouped as rural areas (Gangwon, Chungbuk, Chungnam, Jeonbuk, Jeonnam, Gyeongbuk, Gyeongnam and Jeju) and urban areas (Seoul, Gyeonggi, Busan, Daegu, Incheon, Gwangju, Daejeon and Ulsan).
‖Sufficient Ca intake was indicated as 'yes' when daily Ca intake of the participants was equal to or greater than the Recommended Daily Allowance[10].
¶Moderate physical activity was indicated as 'yes' when the participant engaged in moderate-intensity physical activity for more than 20 min at a time and more than 3 times/week.

East Asian populations including Korean, Chinese and Japanese also seem to be predisposed to low vitamin D status. As with Korean adolescents, high prevalence of vitamin D deficiency was reported in Chinese adolescent girls living in Beijing (45 %)[25] and Japanese young women (42 %)[26]. The prevalence of adolescents with serum 25(OH)D ≥75 nmol/l was only 3·8 % in our Korean adolescents, which was about one-eighth that reported

https://doi.org/10.1017/S1368980012004703 Published online by Cambridge University Press

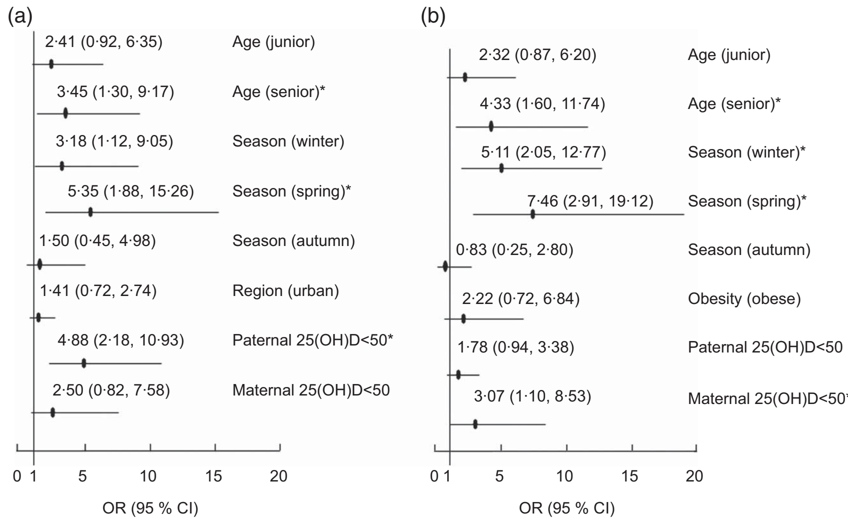

Fig. 3 Odds ratios and 95 % confidence intervals for vitamin D deficiency from multivariate regression analyses by sex (a, boys; b, girls): adolescents (*n* 2062; 1095 boys, 967 girls) aged 10–18 years, Korean National Health and Nutrition Examination Survey (KNHANES) 2008–2009. References for each predictor: age = elementary school (10–12 years); season = summer; region = rural; paternal 25-hydroxyvitamin D (25(OH)D) level ≥50 nmol/l; maternal 25(OH)D level ≥50 nmol/l; obesity = normal weight (age- and sex-specific BMI <85th percentile). $^*P < 0{\cdot}05$

(30 %) among US children[6]. Several factors can explain low vitamin D status in East Asian adolescents. Inadequate sunlight exposure was prevalent among Chinese adolescents and their skin exposure to UV light mainly determined vitamin D status[25]. The vitamin D and Ca intakes from food sources were often much lower than the RNI for Chinese adolescents, and their low Ca intake was significantly associated with vitamin D deficiency[25]. The situation is similar in Korean adolescents, which will be discussed in detail later.

Consistent with other studies[7,22], mean serum 25(OH)D value was the highest in summer and the lowest in spring and winter in the present study. Winter/spring season was the most potent predictor of 25(OH)D deficiency in Korean adolescents.

Our study demonstrated that girls had a higher prevalence of vitamin D deficiency than boys, and this pattern was consistent through all age groups. Some studies have supported a higher prevalence of 25(OH)D deficiency in girls than in boys[6,19], while other studies have not found any gender differences[8,27]. We found that girls had less physical activity and lower Ca intake as %RNI compared with boys. Also, the consumption of vitamin D from food sources (such as milk, eggs and oily fish) was lower in girls than in boys (data not shown), which was consistent with US studies[28]. We speculate that all of these factors could be possible explanations for a higher prevalence of vitamin D deficiency in girls than in boys.

There seems to be a high probability of familial correlation in vitamin D status. Poor maternal vitamin D status has been implicated in vitamin D deficiency of breast-feeding infants[16,29], and a few studies with small sample size have shown higher familial history of vitamin D deficiency in rachitic children than in non-rachitic children[30,31]. However, the association between adolescent vitamin D deficiency and parental vitamin D status has not been previously reported in a population study. We found a strong association of parent–adolescent vitamin D status. Also, parental vitamin D deficiency was an independent predictor for adolescent vitamin D deficiency independently from season, age, region and obesity. Possible explanations for the parent–adolescent association could be the cultural and dietary habits shared by family members, or genetic factors involved in vitamin D-endocrine metabolism such as dermal production[32] or degradation of vitamin D[33]. Our findings support the suggestion that a strong familial tendency of vitamin D deficiency in Korea warrants vitamin D screening for family members of deficient individuals.

Few studies have shown that older children were more likely to be 25(OH)D deficient[6,22]. The prevalence of vitamin D deficiency in adolescents increased with age, reaching the highest in senior high school students (19·5 % in boys, 25·1 % in girls), and age was one of the most potent predictors of vitamin D deficiency in the present study. The main factor that explains the association between age and vitamin D status seems to be sunlight exposure. The students in higher grades tend to spend much of the daytime indoors for study, and the proportion of physical education in the curriculum is reduced. Moreover, most physical training programmes for high school students are carried out in a gymnasium, which limits UVB exposure. Media promotion announcing the high prevalence of vitamin D deficiency in Korean high school students and long-term public health plans are needed to improve sunlight exposure in Korean adolescents by schools and government.

Physical inactivity, previously reported as an important factor for vitamin D deficiency[15,34], was not an independent factor for vitamin D deficiency in the present study. However, the questionnaire conducted by KNHANES did not query where individuals do physical activity, if it is indoor or outdoor activity; therefore it has some limitation in reflecting sunlight exposure. Also, half of the participants had low physical activity of less than 1 h/week. Therefore it might not have an effect as a predictor for vitamin D deficiency in our study.

Obesity has been cited as a risk factor for vitamin D deficiency because the body fat sequesters the fat-soluble vitamin D, resulting in decreased bioavailability from cutaneous and dietary sources[35], and obese people may have a more sedentary, indoor lifestyle[36]. Previous studies in adults[37,38] and children[7,39] have shown an inverse correlation between BMI and serum 25(OH)D levels. However, we could not find a correlation between obesity status and 25(OH)D concentration. The prevalence of obesity was low, at 4·7 % of participants in our study, which limits the ability to demonstrate the effect of obesity in vitamin D deficiency.

Dietary Ca intake may play a role in vitamin D metabolism. Insufficient intake of Ca can induce mild hyperparathyroidism and consequent elevation of 1,25-dihydroxyvitamin D production, which enhances the catabolism of 25(OH)D and lowers circulating vitamin D[16]. A study from China found that adolescent girls who had Ca intake below 280 mg/d showed a 50 % higher risk of vitamin D deficiency[25]. We found that the mean value for Ca intake as %RNI was as low as 53·8 % (Table 1) and insufficient Ca intake was a significant factor for vitamin D deficiency in boys (Table 3). As milk is a main source of both Ca and vitamin D, low Ca intake might be a reflection of limited intake of vitamin D in Korean adolescents.

The Dietary Reference Intakes of vitamin D from the Institute of Medicine (2010) and the American Academy of Pediatrics state that the Estimated Average Requirement (EAR) of vitamin D is 10 μg/d for all ages and the Adequate Intake (AI) is 15 μg/d for children and adolescents[17,18]. However, in the Dietary Reference Intakes of vitamin D for Koreans published in 2010, the AI of vitamin D is 5 μg/d for children and adolescents[10]. Several experts suggest that, without adequate sunlight exposure, children and adolescents require 25 μg/d to achieve adequate levels[15]. As we previously reported, only 14·2 % of Korean children and adolescents use multivitamin supplements[40] and most of the over-the-counter multivitamin or vitamin D supplements in Korea provide 2–5 μg of vitamin D_2 or D_3 daily[41], which is too low to meet the suggested vitamin D intakes. Further research is needed to establish the AI of vitamin D to maintain sufficient vitamin D levels for the Korean population.

There were some limitations in our study. First, the study was cross-sectional and therefore causality cannot be inferred. Second, we did not use validated tools to measure sunlight exposure. Last, dietary vitamin D intake was not analysed in the KNHANES, so we could not assess the effect of vitamin D intake. Nevertheless, to our knowledge, the present study is the first one that has demonstrated the association between parental vitamin D deficiency and the risk of adolescent vitamin D deficiency using the most recent nationwide data.

Conclusions

Vitamin D insufficiency was highly prevalent in healthy Korean adolescents. Winter/spring season, senior high school students and parental vitamin D deficiency were associated with higher risk of vitamin D deficiency. We suggest that adequate outdoor activity and vitamin D intake should be emphasized in Korean adolescents, and family screening of vitamin D for deficient individuals seems to be important.

Acknowledgements

Sources of funding: This research was supported by the 2012 Inje University research grant. *Conflicts of interest:* There are no potential conflicts of interest. *Authors' contributions:* S.H.K., R.N. and M.J.P. were responsible for the conception and design of the study. M.K.O. performed the data analysis and all authors had a role in interpretation of the data. S.H.K. and M.J.P. drafted the manuscript, and R.N. revised and commented on the draft. All authors read and approved the final manuscript.

References

1. DeLuca HF (2004) Overview of general physiologic features and functions of vitamin D. *Am J Clin Nutr* **80**, Suppl. 6, S1689–S1696.
2. Tangpricha V, Pearce EN, Chen TC *et al.* (2002) Vitamin D insufficiency among free-living healthy young adults. *Am J Med* **112**, 659–662.
3. Huh K, Woo MK, Yoon JR *et al.* (2010) Clinical characteristics of vitamin D deficiency rickets in infants and preschool children. *Korean J Pediatr* **53**, 152–157.
4. Bikle D (2009) Nonclassic actions of vitamin D. *J Clin Endocrinol Metab* **94**, 26–34.
5. Holick MF (2004) Vitamin D: importance in the prevention of cancers, type 1 diabetes, heart disease, and osteoporosis. *Am J Clin Nutr* **79**, 362–371.
6. Kumar J, Muntner P, Kaskel FJ *et al.* (2009) Prevalence and associations of 25-hydroxyvitamin D deficiency in US children: NHANES 2001–2004. *Pediatrics* **124**, 362–370.
7. Rockell JE, Green TJ, Skeaff CM *et al.* (2005) Season and ethnicity are determinants of serum 25-hydroxyvitamin D concentrations in New Zealand children aged 5–14 y. *J Nutr* **135**, 2602–2608.
8. Marwaha RK, Tandon N, Reddy DR *et al.* (2005) Vitamin D and bone mineral density status of healthy schoolchildren in northern India. *Am J Clin Nutr* **82**, 477–482.
9. Moon JS, Lee SY, Nam CM *et al.* (2008) 2007 Korean National Growth Charts: review of developmental process and an outlook. *Korean J Pediatr* **51**, 1–25.

10. Seo JS, Kim JH, Cho SH *et al.* (2010) Vitamin D. In *Dietary Reference Intakes for Koreans, 2nd ed.*, pp. 165–168 [YS Choi and HK Moon, editors]. Seoul: The Korean Nutrition Society.
11. Al-Hazzaa HM (2007) Health-enhancing physical activity among Saudi adults using the International Physical Activity Questionnaire (IPAQ). *Public Health Nutr* **10**, 59–64.
12. Harkness LS & Cromer BA (2005) Vitamin D deficiency in adolescent females. *J Adoles Health* **37**, E75.
13. Greer FR (2009) Defining vitamin D deficiency in children: beyond 25-OH vitamin D serum concentrations. *Pediatrics* **124**, 1471–1473.
14. Heaney RP (2004) Functional indices of vitamin D status and ramification of vitamin D deficiency. *Am J Clin Nutr* **80**, Suppl. 6, S1706–S1709.
15. Holick MF, Binkley NC, Bischoff-Ferrari HA *et al.* (2011) Evaluation, treatment, and prevention of vitamin D deficiency: an Endocrine Society clinical practice guideline. *J Clin Endocrinol Metab* **96**, 1911–1930.
16. Pettifor JM (2004) Nutritional rickets: deficiency of vitamin D, calcium, or both? *Am J Clin Nutr* **80**, Suppl. 6, S1725–S1729.
17. Wagner CL & Greer FR (2008) Prevention of rickets and vitamin D deficiency in infants, children, and adolescents. *Pediatrics* **122**, 1142–1152.
18. Ross AC, Manson JE, Abrams SA *et al.* (2011) The 2011 report on dietary reference intakes for calcium and vitamin D from the Institute of Medicine: what clinicians need to know. *J Clin Endocrinol Metab* **96**, 53–58.
19. El-Hajj Fuleihan G, Nabulsi M, Choucair M *et al.* (2001) Hypovitaminosis D in healthy schoolchildren. *Pediatrics* **107**, E53.
20. Institute of Medicine (2011) *Dietary Reference Intakes for Calcium and Vitamin D*. Washington, DC: National Academies Press.
21. Looker AC, Dawson-Hughes B, Calvo MS *et al.* (2002) Serum 25-hydroxyvitamin D status of adolescents and adults in two seasonal subpopulations from NHANES III. *Bone* **30**, 771–777.
22. Prentice A (2008) Vitamin D deficiency: a global perspective. *Nutr Rev* **66**, Suppl. 10, S153–S164.
23. Mark S, Gray-Donald K, Delvin EE *et al.* (2008) Low vitamin D status in a representative sample of youth from Québec, Canada. *Clin Chem* **54**, 1283–1289.
24. Neyestani TR, Hajifaraji M, Omidvar N *et al.* (2012) High prevalence of vitamin D deficiency in school-age children in Tehran, 2008: a red alert. *Public Health Nutr* **15**, 324–330.
25. Du X, Greenfield H, Fraser DR *et al.* (2001) Vitamin D deficiency and associated factors in adolescent girls in Beijing. *Am J Clin Nutr* **74**, 494–500.
26. Nakamura K, Nashimoto M, Matsuyama S *et al.* (2001) Low serum concentrations of 25-hydroxyvitamin D in young adult Japanese women: a cross sectional study. *Nutrition* **17**, 921–925.
27. Weng FL, Shults J, Leonard MB *et al.* (2007) Risk factors for low serum 25-hydroxyvitamin D concentrations in otherwise healthy children and adolescents. *Am J Clin Nutr* **86**, 150–158.
28. Moore C, Murphy MM, Keast DR *et al.* (2004) Vitamin D intake in the United States. *J Am Diet Assoc* **104**, 980–983.
29. Park MJ, Namgung R, Kim DH *et al.* (1998) Bone mineral content is not reduced despite low vitamin D status in breast milk-fed infants versus cow's milk based formula-fed infants. *J Pediatr* **132**, 641–645.
30. Thacher TD, Fischer PR, Pettifor JM *et al.* (2000) Case–control study of factors associated with nutritional rickets in Nigerian children. *J Pediatr* **137**, 367–373.
31. Bener A & Hoffmann GF (2010) Nutritional rickets among children in a sun rich country. *Int J Pediatr Endocrinol* **2010**, 410502.
32. Holick MF, Uskokovic M, Henley JW *et al.* (1980) The photoproduction of 1α,25-dihydroxyvitamin D_3 in skin: an approach to the therapy of vitamin-D-resistant syndromes. *N Engl J Med* **303**, 349–354.
33. Awumey EM, Mitra DA, Hollis BW *et al.* (1998) Vitamin D metabolism is altered in Asian Indians in the southern United States: a clinical research center study. *J Clin Endocrinol Metab* **83**, 169–173.
34. Foo LH, Zhang Q, Zhu K *et al.* (2009) Relationship between vitamin D status, body composition and physical exercise of adolescent girls in Beijing. *Osteoporos Int* **20**, 417–425.
35. Wortsman J, Matsuoka LY, Chen TC *et al.* (2000) Decreased bioavailability of vitamin D in obesity. *Am J Clin Nutr* **72**, 690–693.
36. Rajakumar K, Fernstrom JD, Holick MF *et al.* (2008) Vitamin D status and response to vitamin D(3) in obese vs. non-obese African American children. *Obesity (Silver Spring)* **16**, 90–95.
37. Kamycheva E, Joakimsen RM & Jorde R (2003) Intake of calcium and vitamin D predicts body mass index in the population of northern Norway. *J Nutr* **133**, 102–106.
38. Arunabh S, Pollack S, Yeh J *et al.* (2003) Body fat content and 25-hydroxyvitamin D levels in healthy women. *J Clin Endocrinol Metab* **88**, 157–161.
39. Gordon CM, DePeter KC, Feldman HA *et al.* (2004) Prevalence of vitamin D deficiency among healthy adolescents. *Arch Pediatr Adolesc Med* **158**, 531–537.
40. Huh K & Park MJ (2009) Questionnaire-based analysis of growth-promoting attempts among children visiting a university growth clinic. *Korean J Pediatr* **52**, 576–580.
41. Yang HR, Seo JW, Kim YJ *et al.* (2009) Recent concepts on vitamin D in children and adolescents. *Korean J Pediatr* **52**, 1082–1089.