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ORIGINAL ARTICLE

Association Between Serum Vitamin D and Metabolic Risk Factors in Korean Schoolgirls

Han Byul Jang [a], Hye-Ja Lee [a], Ju Yeon Park [a], Jae-Heon Kang [b], Jihyun Song [a,*]

[a]*Division of Metabolic Diseases, Korea National Institute of Health, Osong, Korea.*
[b]*Department of Family Medicine, Obesity Research Institute, Seoul-Paik Hospital, Inje University, Seoul, Korea.*

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Abstract
Objectives: Vitamin D, a key regulator of bone metabolism, has been recently been linked with energy homeostasis and metabolic disorders in western countries. However, few studies have focused on the association of vitamin D with metabolic risk factors among Asian children. We studied the prevalence of vitamin D insufficiency and the association of 25-hydroxyvitamin D [25(OH)D] with metabolic risk factors in Korean schoolgirls.
Methods: The sample consisted of 320 13-year-old girls recruited from two middle schools in the city of Gwacheon, Korea (latitude 37°N), in July 2011. Anthropometric and blood biochemistry data were obtained for this cross-sectional observational study. We also obtained lifestyle data from questionnaires and dietary data from 3-day food diaries.
Results: Vitamin D deficiency [25(OH)D $<$ 20 ng/mL] was noted in 63.8% of participants. The mean 25(OH)D level was not significantly lower in the overweight group. Level of physical activity and vitamin D intake did not significantly affect 25(OH)D. However, 25(OH)D levels were positively correlated with milk intake and negatively correlated with soft drink intake. Serum 25(OH)D had a negative relationship with fasting glucose and insulin resistance index (homeostasis model assessment-insulin resistance; HOMA-IR) after adjustment for physical activity and body mass index z score ($r = -0.144$, $p = 0.015$), and with metabolic risk score similarly ($r = -0.141$, $p = 0.012$). Levels of insulin, HOMA-IR, and systolic blood pressure were higher in girls with deficient 25(OH)D levels than in those with sufficient levels.
Conclusion: We found that low 25(OH)D levels were associated with higher blood glucose and insulin resistance. Korean girls with low 25(OH)D levels could be at increased risk for metabolic disorders.

*Corresponding author.
E-mail: jhsong10@korea.kr

1. Introduction

The prevalence of obesity is high in western and Asian countries including Korea [1]. The high prevalence of obesity among children and adolescents is particularly concerning because they are at risk for metabolic complications of obesity including metabolic syndrome (MetS) and type 2 diabetes in childhood and later life [2,3]. MetS risk factors include abdominal obesity, high blood pressure, high glucose, high insulin resistance (IR), and low high-density lipoprotein (HDL) levels. It is crucial to identify modifiable risk factors involved in the early development of metabolic disorders to guide future prevention and treatment efforts.

Vitamin D deficiency is also prevalent worldwide [4]. In humans, vitamin D is obtained primarily from exposure to ultraviolet (UV) B radiation and to a lesser extent from dietary and supplemental sources. Although vitamin D has been traditionally considered important to skeletal health, recent studies have reported that vitamin D also has beneficial effects on extraskeletal tissues [5]. Several studies have suggested possible links between vitamin D and cardiovascular disease risk [6,7], diabetes [8,9], hypertension [10], and dyslipidemia [11,12].

Most studies of vitamin D deficiency and metabolic disorders have focused on adults with diabetes or obesity. Although diabetes and MetS frequently occur in later life, pathological evidence suggests that the precursors of MetS, diabetes, and cardiovascular disease originate in childhood [13,14]. A significant association between vitamin D and metabolic risk factors in adolescence suggests that the successful repletion of vitamin D has the potential to improve the metabolic risk profile during adolescence and to lower the risk of developing diabetes in adulthood. However, only a few studies have investigated the association between vitamin D and risk factors for MetS in childhood. Adolescent girls are particularly more prone to vitamin D deficiency because of their rapid bone mineralization rate during puberty, their lower exposure to the sun and limited outdoor activities, and the decrease in milk consumption that often occurs during adolescence [15,16]. Inadequate dietary habits, including low dairy product intake, are implicated as risk factors for health status [17], and research documenting dietary habits and health status among Asian girls could help identify potential areas for educational intervention.

Vitamin D deficiency is highly prevalent worldwide, therefore, establishing an association between vitamin D status and metabolic risk factors may have widespread implications for public health. However, little evidence is available for the association of vitamin D with metabolic risk factors among children and adolescents of Asian origin. We investigated the prevalence of vitamin D insufficiency and the association of 25-hydroxyvitamin D [25(OH)D] with metabolic risk factors among Korean girls.

2. Materials and Methods

2.1. Study population

A total of 320 13-year-old girls were recruited from two middle schools in the city of Gwacheon (latitude 37°N) in July 2011. The study was conducted as part of the Korean Children−Adolescents Study (KoCAS), which has monitored a group of children annually since their entry into elementary school at age 7 years in the city of Gwacheon, Kyunggi Province, Korea. The objective of this pediatric cohort study is to identify early risk factors for obesity and associated metabolic diseases in urban Korean children and adolescents. Girls were excluded if they were taking medication that might affect biochemical factors or if they had abnormally high insulin levels. The study was approved by the Institutional Review Board of Seoul-Paik Hospital, Inje University, and the Korea Centers for Disease Control and Prevention (KCDC). Informed consent was obtained from the children's parents.

2.2. Anthropometric measurements

Body height was measured using an automatic stadiometer (model DS 102; Jenix, Seoul, Korea), and body weight was measured via bioimpedence analysis using a body composition analyzer (BC-418; Tanita, Tokyo, Japan). Body mass index (BMI) was calculated by dividing the weight in kilograms by height in meters squared, and the BMI z-score was calculated based on Korean reference data [18]. Waist circumference (WC) was measured at the midpoint between the lower border of the ribcage and the iliac crest using a nonelastic tape measure. All individuals with a BMI $\geq 85^{th}$ percentile were classified as overweight using data from the 2007 KCDC growth chart. Blood pressure was measured twice on the right arm using a mercury sphygmomanometer while the participant was resting in a seated position.

2.3. Biochemical analyses

Blood samples were collected from an antecubital vein into vacutainer tubes after a 12-hour overnight fast. Within 30 minutes, aliquots of plasma and serum were separated and stored at 80 °C until further analysis. Triglyceride (TG), total cholesterol (TC), and HDL−cholesterol (HDL-C) levels were measured via enzymatic assays and an autoanalyzer (model 7600 II; Hitachi, Tokyo, Japan). Fasting serum glucose levels were measured using the hexokinase method and a glucose analyzer (model 7600 II; Hitachi). Fasting serum insulin levels were measured using an enhanced chemiluminescence immunoassay analyzer (model

E170; Roche, Mannheim, Germany). IR was estimated from fasting serum measurements using the homeostasis model assessment-insulin resistance (HOMA-IR) [insulin (μIU/mL) X glucose (mmol/L) / 22.5] and insulin sensitivity was estimated by QUICKI [1 / (log insulin (μIU/mL) + log glucose (mg/dL))] [19]. Serum 25(OH)D levels were measured using a gamma counter (1470 Wizard; Perkin−Elmer, Turku, Finland) with a radioimmunoassay (DiaSorin, Stillwater, MN, USA).

2.4. Dietary intake and physical activity

Typical dietary intake for each participant was estimated based on 3-day food diary records documented for 3 consecutive days (2 weekdays, 1 weekend day), which were completed by 279 adolescents. Dietary questionnaires certified by Inje University Paik Hospital were checked by researchers trained to determine whether records contained sufficient information. The nutrient database used to calculate total nutrient intake was obtained from Food Values [20], and calculated to the average daily dietary intake. Adequate intake (AI) of vitamin D was assessed using the Dietary Reference Intake for Koreans [21] released in 2010. Information about dietary habits was obtained from questionnaires that included the frequency of intake per week of milk, soft drinks, fruit, vegetables, Korean noodles (Ramyeon), and fast food. "Skip breakfast" was quantified as the number of days that breakfast was skipped per week. The level of physical activity (PA) was assessed by responses to modified standardized questionnaires, and participants were divided into two physical groups: low (<4 times per week) and high (>4 times per week) [22].

2.5. Statistical analyses

Statistical analyses were performed with SAS software (version 9.1; SAS Institute, Cary, NC, USA), and values are presented as mean ± standard deviation (SD) for continuous variables or as raw numbers and percentages for categorical variables. Variables that were not normally distributed were log-transformed before analysis [25(OH)D, glucose, insulin, HOMA-IR, QUICKI, TG, TC and HDL-C levels]. MetS was defined based on the International Diabetes Federation (IDF) definition, and we constructed a composite metabolic risk score defined by a continuously distributed variable [23]. This variable was derived from five metabolic factors: BMI, systolic blood pressure (SBP), TG, HDL-C, and HOMA-IR. Each risk factor was standardized to a z-score, which indicates the distance of a particular value from the mean in units of SD: (observed value − mean) / SD [24]. The metabolic risk score (z-score) was calculated as the sum of five z-scores. Mean values between groups categorized by 25(OH)D concentration with a cutoff value of <20 ng/mL, used to define deficiency, were compared using Student's t test. The χ^2 test and Fisher's exact test were used to compare prevalence data, and Pearson correlation coefficients were used to evaluate the relationship between 25(OH)D and metabolic risk factors. Simple linear regression and multiple stepwise regression analyses were performed for dietary habits data in relation to 25(OH)D. P values <0.05 were considered to be statistically significant.

3. Results

A total of 320 Korean girls were studied in July 2011. Their mean age was 13.0 years (range: 12.4−14.5 years) and mean BMI was 19.6 kg/m^2. The prevalence of overweight girls, defined as those with BMI ≥85th percentile, was 11.6%, and 76% participated in <2 hours exercise per week. The mean energy intake was 1675.8 kcal, with 3.0 μg vitamin D intake. Approximately 86.7% of girls had a less than AI of vitamin D (5 μg/day).

3.1. Association of serum 25(OH)D levels with lifestyle

As shown in Table 1, the mean serum 25(OH)D level was 19.4 ng/mL, and 63.8% of girls were vitamin D deficient [25(OH)D < 20 ng/mL]. Mean serum 25(OH)D levels did not differ significantly between the categories of BMI (nonoverweight/overweight), PA (low/high), nutrient supplement user (yes/no), and vitamin D intake (<AI/≥AI).

Table 2 presents dietary data. When possible, modulators of serum vitamin D levels such as BMI-z score, vitamin D intake, PA, and dietary habits are listed together. Three of the strongest predictors of 25(OH)D levels were milk intake ($p = 0.004$), soft drink intake ($p = 0.030$), and fruit intake ($p = 0.053$). 25(OH)D levels and milk intake were positively related but soft drink and fruit intake were negatively related. Taken together, milk, soft drinks, and fruit intake predict the 25(OH)D level with an R^2 of 0.067.

3.2. Association of serum 25(OH)D levels with metabolic risk factors

Significant inverse relationships appeared between 25(OH)D levels and glucose, insulin, and HOMA-IR, and a positive relationship appeared with HDL-C (Table 3). After adjustment for PA and BMI-z score, the correlations with glucose, insulin, HOMA-IR, and QUICKI remained statistically significant. Serum 25(OH)D levels had a negative relationship with metabolic risk score ($r = -0.141, p = 0.012$).

Table 4 summarizes the clinical and biochemical characteristics of the girls stratified according to 25(OH)D level: <20 ng/mL (deficiency) and ≥20 ng/mL (sufficiency). The deficiency group had slightly higher mean WC and glucose levels compared to those in the sufficiency group, although this trend was not statistically significant. Although the mean QUICKI level was lower

Table 1. Serum 25(OH)D levels in girls according to body weight and lifestyle factors

Variable	*n*	25(OH)D*	*p*
Overall†	320	19.4 ± 4.6	
Deficiency	204	16.7 ± 2.3	<0.0001
Sufficiency	116	24.0 ± 3.8	
BMI category‡			
Not overweight	283	19.4 ± 4.8	0.6268
Overweight	37	18.8 ± 3.0	
Physical activity§			
Low	215	19.2 ± 4.8	0.3068
High	68	19.6 ± 4.0	
Nutrient supplement user			
Yes	133	19.0 ± 4.4	0.1046
No	187	19.9 ± 4.8	
Vitamin D intake‖			
<AI	242	19.1 ± 4.5	0.3706
≥AI	37	19.6 ± 3.8	

*Log transformations; †25(OH)D concentrations: deficiency, 25(OH)D < 20 ng/mL; sufficiency, 25(OH)D ≥ 20 ng/mL; ‡Overweight: BMI ≥ 85th percentile (according to the 2007 Korea Centers for Disease Control BMI-for-age growth chart); §Physical activity: low, ≤4 times/week; high, >4 times/week; ‖Vitamin D AI criteria: 5 μg/day (according to the 2010 dietary reference intake for Koreans, Korean Nutrition Society). Values are expressed as mean ± SD. 25(OH)D = 25-hydroxyvitamin D; AI = adequate intake; BMI = body mass index; SD = standard deviation.

in the deficiency group than in the sufficiency group, mean insulin, HOMA-IR, and SBP levels were higher in the deficiency group than in the sufficiency group. The metabolic risk score was calculated as the sum of five z-scores of BMI, SBP, TG, HDL-C, and HOMA-IR, thus, the finding that girls with vitamin D deficiency had higher metabolic risk scores suggests that a low vitamin D status could lead to a metabolic disordered state ($p = 0.024$). The mean dietary intake of energy, vitamin D, and calcium did not differ significantly between the two groups.

Table 5 presents the prevalence of individual metabolic abnormalities (defined based on the IDF definition) by vitamin D status. The prevalence of high glucose (≥100 mg/dL) differed significantly between the two groups ($p = 0.031$). Among the 204 girls in the vitamin D deficiency group, 10.2% had high glucose levels, whereas only 3.5% of the 116 girls in the vitamin D sufficiency group had high glucose levels. Six girls with low HDL-C belonged to the vitamin D deficiency group. Three girls (0.9%) had MetS (more than three metabolic abnormalities); they were all in the vitamin D deficiency group (data not shown). The vitamin D deficiency group included significantly more girls with more than one metabolic abnormality than did the vitamin D sufficiency group (32.8% vs. 20.7%, $p = 0.021$; data not shown).

Table 2. Variables predicting serum 25(OH)D

		Simple linear regression*			Multiple stepwise regression†		
Variable	*n*	β	r^2	*p*	β	r^2	*p*
Milk‡	310	0.0238	0.0272	0.0036	0.0233	0.0238	0.0009
Soft drinks‡	310	−0.0397	0.0153	0.0299	−0.0445	0.0481	
Fruit‡	308	−0.0184	0.0122	0.0528	−0.0224	0.0667	
Vegetables‡	311	−0.0042	0.0007	0.6320			
Korean noodles‡	311	−0.0143	0.0015	0.4914			
Fast food‡	309	−0.0103	0.0007	0.6381			
Skip breakfast§	301	−0.0013	0.0001	0.8578			
BMI-z score§	320	−0.0178	0.0049	0.2118			
Physical activity§	310	0.0329	0.0037	0.3068			
Dietary vitamin D intake	279	0.0061	0.0072	0.1579			

*Simple linear regressions are for the individual independent variables indicated; †For multiple stepwise regression analysis, only the three independent variables incorporated into the model are listed, and the r^2 values displayed are cumulative; ‡Milk, soft drinks, fruit, vegetables, Korean noodles, and fast food, frequency of intake for a week; §Skip breakfast, skipped breakfast days for a week; physical activity, <4 times per week/>4 times per week. 25(OH)D = 25-hydroxyvitamin D.

Table 3. Relationship between serum 25(OH)D and metabolic risk factors

	Unadjusted		Adjusted*	
	r	*p*	*r*	*p*
Fasting glucose†	−0.1833	0.0010	−0.1748	0.0033
Fasting insulin†	−0.1617	0.0037	−0.1237	0.0382
HOMA-IR†	−0.1819	0.0011	−0.1441	0.0154
QUICKI†	0.1733	0.0019	0.1369	0.0217
SBP	−0.0910	0.1044	−0.0547	0.3612
DBP	−0.0534	0.3415	−0.0138	0.8181
TG†	−0.1032	0.0653	−0.0896	0.1341
TC†	0.0319	0.5703	0.0199	0.7399
HDL-C†	0.1514	0.0066	0.1140	0.0563

*Adjusted for physical activity and BMI-z score; †Log transformation. 25(OH)D = 25-hydroxyvitamin D; DBP = diastolic blood pressure; HDL-C = high-density lipoprotein−cholesterol; HOMA-IR = homeostasis model assessment-insulin resistance; QUICKI = quantitative insulin sensitivity check index; SBP = systolic blood pressure; TC = total cholesterol; TG = triglyceride.

4. Discussion

The increasing incidence of obesity, IR, and metabolic disorders in children and adolescents prompted us to assess whether there is an association between vitamin D status and glucose and lipid homeostasis in apparently healthy Asian children and adolescents. We studied the prevalence of vitamin D deficiency in schoolgirls living in urban Korea, in East Asia. We also tried to identify major lifestyle-related factors that influence serum vitamin D levels, and assessed the association of 25(OH)D with IR and metabolic risk factors in Korean schoolgirls.

In many countries throughout all continents, 50% of the population has vitamin D deficiency [25]. Researchers continue to debate the definition of vitamin D deficiency, but most agree that a serum concentration of 25(OH)D < 20 ng/mL is considered to be deficient [4]. As previously reported, vitamin D deficiency is very common. The mean level in adults is 19.9 ng/mL, and the prevalence of vitamin D deficiency is 41.6% in the US [26]. The Korea National Health and Nutrition

Table 4. Characteristics of participants by serum 25(OH)D concentrations

	All (*n* = 320)	Deficiency <20 ng/mL (*n* = 204)	Sufficiency ≥20 ng/mL (*n* = 116)	*p*
BMI (kg/m^2)	19.6 ± 2.7	19.8 ± 2.7	19.3 ± 2.6	0.1755
BMI-z	0.05 ± 0.91	0.10 ± 0.88	−0.41 ± 0.95	0.1686
WC (cm)	70.3 ± 7.1	70.8 ± 7.0	69.4 ± 7.2	0.0901
SBP (mmHg)	107.1 ± 9.5	108.0 ± 9.3	105.5 ± 9.7	0.0199
DBP (mmHg)	69.5 ± 8.4	70.0 ± 8.2	68.8 ± 8.7	0.2109
Fasting glucose (mg/dL)	88.5 ± 7.5	89.0 ± 7.7	87.5 ± 6.9	0.1088*
Fasting insulin (μIU/mL)	10.5 ± 4.7	11.0 ± 5.0	9.7 ± 4.0	0.0358*
HOMA-IR	2.32 ± 1.10	2.44 ± 1.17	2.11 ± 0.93	0.0325*
QUICKI	0.149 ± 0.01	0.148 ± 0.01	0.151 ± 0.127	0.0454*
TG (mg/dL)	76.5 ± 35.3	77.5 ± 36.6	74.7 ± 32.8	0.5532*
TC (mg/dL)	166.4 ± 27.2	165.5 ± 29.1	168.0 ± 23.6	0.2681*
HDL-C (mg/dL)	59.0 ± 10.4	58.4 ± 10.4	60.1 ± 10.3	0.1373*
Metabolic risk score‡	0.00 ± 2.44	0.23 ± 2.51	−0.41 ± 2.28	0.0241
Dietary intake (*n* = 279)				
Energy (kcal)	1675.8 ± 301.7	1696.4 ± 298.9	1635.3 ± 304.8	0.1098
Vitamin D (μg)	3.0 ± 3.1	3.0 ± 2.5	3.2 ± 4.0	0.5914
AI of vitamin D (%)	37 (13.26)	24 (12.97)	13 (13.83)	0.8419†
Ca (mg)	466.4 ± 178.7	468.4 ± 180.9	462.3 ± 175.0	0.7884

**p* values between deficiency group and sufficiency group were obtained by *t* test for log transformed variable; †*p* values between deficiency group and sufficiency group were obtained by χ^2 test; ‡Metabolic risk score (z-score) was calculated as the sum of the five z-scores (BMI, SBP, TG, HDL-C, and HOMA-IR). Values are expressed as the mean ± SD or *n* (%). 25(OH)D = 25-hydroxyvitamin D; AI = adequate intake; BMI = body mass index; DBP = diastolic blood pressure; HDL-C = high-density lipoprotein−cholesterol; HOMA-IR = homeostasis model assessment-insulin resistance; QUICKI = quantitative insulin sensitivity check index; SBP = systolic blood pressure; SD = standard deviation; TC = total cholesterol; TG = triglyceride; WC = waist circumference.

Table 5. Prevalence of individual metabolic abnormalities among girls by vitamin D status

	n (all)	Deficiency *n* = 204 (%)	Sufficiency *n* = 116 (%)	*p*
Abdominal obesity (WC ≥ P90*)	52	38 (18.5)	14 (12.1)	0.1308
High BP (≥130/85 mmHg)	18	12 (5.9)	6 (5.2)	0.7988
High glucose (≥100 mg/dL)	25	21 (10.2)	4 (3.5)	0.0306
High TG (≥150 mg/dL)	14	10 (4.9)	4 (3.5)	0.7771
Low HDL-C (<40 mg/dL)	6	6 (2.9)	0 (0.0)	–

*WC ≥ 90th percentile (reference to the 2007 KCDC WC-for-age). *p* values between deficiency group and sufficiency group were obtained by χ^2 test. BP = blood pressure; HDL-C = high-density lipoprotein−cholesterol; TG = triglyceride; WC = waist circumference.

Examination Survey revealed that mean vitamin D levels in Korea (21.2 ng/mL in males and 18.2 ng/mL in females) are similar to those in American adults; and vitamin D deficiency was found in 47.3% of males and 64.5% of females [27]. In this study, the mean serum 25(OH)D level was 19.4 ng/mL, and 63.8% of girls had vitamin D deficiency. The mean vitamin D level in our study was lower than previously reported levels in children and adolescents [28−31], although the prevalence of overweight/obesity among our participants was relatively low compared with previous studies. Several studies have reported that obesity is a risk factor for vitamin D deficiency [30−32] because of the decreased bioavailability of vitamin D due to its deposition in body fat compartments [33]. However, we found no relationship between BMI and vitamin D levels, perhaps due to the low prevalence of overweight/obese girls. A slight but not significant reduction of 25(OH)D level was observed in the low PA group compared to that in the high PA group, whereas previous studies [34−36] have reported that more PA could increase vitamin D levels through increased sun exposure.

To identify the potential predictors of decreased vitamin D levels, we analyzed serum 25(OH)D level, dietary data, BMI-z, and PA together. The study population included a relatively low percentage of overweight children, therefore, the frequency of milk, soft drink, and fruit intake could be used as the three most influential predictors. A previous study conducted in the US demonstrated that poor dietary habits played a role in the decreased vitamin D levels observed in obese children [31]. In our study, poor dietary habits, especially frequent soft drink intake, was linked with low vitamin D in apparently healthy girls. However, frequency of fast food intake and skipping breakfast were not significantly linked with vitamin D levels. Fortified milk could be the most important source of vitamin D in Korea. Previous studies have associated milk consumption with higher 25(OH)D levels [37], and we also found a significant relationship between the frequency of milk intake and 25(OH)D levels. Although serum vitamin D levels did not vary by vitamin D intake assessed by dietary record, vitamin D intake could be influenced by unhealthy dietary habits such as consuming more soft drinks instead of drinking milk. Healthy dietary habits should be developed to ensure adequate intake of vitamin D and subsequent serum vitamin D levels.

The relationship between 25(OH)D and the prevalence of MetS remains controversial. Studies reporting inverse associations between 25(OH)D and MetS have generally focused on adults or those with high BMI and obesity [14,38]. In this study, our participants had a lower prevalence of MetS (0.9%); perhaps because of their youth (age 13 years) and the low incidence of obesity. Therefore, the prevalence of MetS according to vitamin D levels could not be determined. Although we could not find a relationship between the incidence of MetS and low vitamin D levels, several important components of MetS were associated with 25(OH)D levels in our study. We found significant inverse relationships with glucose, insulin, and HOMA-IR, and positive relationships with QUICKI and HDL-C. After adjustment for PA and BMI-z score, the correlations with glucose, insulin, HOMA-IR, and QUICKI remained statistically significant. When divided into two groups according to 25(OH)D level, the vitamin D deficiency group (<20 ng/mL) had slightly higher, but statistically insignificant, mean WC and glucose levels compared to those in the vitamin D sufficiency group. Mean SBP, insulin, and HOMA-IR levels were higher in the deficiency group than in the sufficiency group. The results of our study generally support previous findings. Most cross-sectional and prospective studies of various populations have found inverse associations between 25(OH)D and glucose, as well as IR [7,9,28,31,34,39]. Sufficient vitamin D levels decrease IR by influencing the expression of insulin receptors, thereby prompting the influx of calcium to promote the insulin response [8].

Previous studies have reported that children and adolescents with MetS have a high prevalence of MetS and type 2 diabetes in adulthood [40], and low levels of MetS variables in childhood are associated with a lower risk for CVD in adulthood [13]. However, because the prevalence rate is relatively low in children and adolescents, the continuous metabolic risk score would be important in epidemiological research to facilitate detection of metabolic disorders. Participants with lower risk values could be considered as having a better MetS profile than those with higher values [41]. In our study,

the vitamin D deficient group had a higher metabolic risk score, and the vitamin D sufficient group had a negative z-score. A higher prevalence of individual metabolic abnormalities such as high glucose and low HDL-C was found among girls with low vitamin D status. Among the 204 vitamin-D-deficient girls, 10.2% had glucose ≥100 mg/dL, whereas among the 116 in the sufficient vitamin D group, only 3.5% had high glucose levels. Six girls with low HDL-C belonged to the vitamin D deficient group. Of the vitamin D deficient girls, 32.8% had more than one metabolic abnormality, and 20.7% of the vitamin D sufficient group had metabolic abnormalities.

In conclusion, consistent with previous findings for adults, 25(OH)D levels in adolescents were inversely related to serum glucose concentration and IR. Vitamin D was weakly related to lipid level, but the vitamin D deficient group had a high prevalence of low HDL-C. These results suggest that Korean schoolgirls with low 25(OH)D levels could be at higher risk for metabolic disorders. As with childhood obesity, a higher metabolic risk score in childhood could persist into adulthood. Vitamin D deficiency may increase the prevalence of individual metabolic abnormalities and continuous metabolic risk scores, therefore, adequate vitamin D status should be ensured in earlier life as well as in adulthood. Healthy dietary habits, such as consuming more milk and fewer soft drinks, could be helpful to achieve an adequate vitamin D level.

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