Association between Serum Vitamin D Status and Metabolic Syndrome in Korean Young Men

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ABSTRACT

HA, C-D., T-K. HAN, S-H. LEE, J-K. CHO, and H-S. KANG. Association between Serum Vitamin D Status and Metabolic Syndrome in Korean Young Men. *Med. Sci. Sports Exerc.*, Vol. 46, No. 3, pp. 513–519, 2014. **Purpose**: This study examined the relations of serum vitamin D levels to body fatness, cardiorespiratory fitness (CRF), and metabolic risk factors in young adults in Korea. **Methods**: Between 2007 and 2009, 799 young men completed a health examination. Body fatness, CRF based on a maximal treadmill exercise test, and measurements of metabolic risk factors were measured in study participants. Participants were classified by serum vitamin D levels as deficient (<12.5 ng·mL^{-1}), insufficient (≥12.5 to <20 ng·mL^{-1}), and sufficient (>20 ng·mL^{-1}) and by CRF as unfit (lowest 20%) and fit (remaining 80%) based on age-standardized distribution of $\dot{V}O_{2max}$ values in this study population. Body fatness, CRF, and metabolic risk factors were evaluated according to serum vitamin D classification. A clustered metabolic risk score was computed by summing standardized scores for waist circumference, resting blood pressures, triacylglycerols, the inverse of high-density lipoprotein cholesterol, glucose, and insulin. **Results**: Linear decreases in body fatness and metabolic risk factors were observed, as was a linear increase for CRF across incremental vitamin D categories. A linear decrease was found in the clustered metabolic risk score across incremental vitamin D categories. Compared to the fit group (reference), the unfit group had significantly higher risks for serum vitamin D inadequacy before and after adjusting for age, smoking, and body fatness parameters. **Conclusions**: The findings of the study suggest that increasing vitamin D intake, eating a healthy diet, and getting enough outdoor physical activity should be promoted as nonpharmacologic means to improve CRF and prevent a clustering of metabolic risk factors in young adults. **Key Words:** VITAMIN D, BODY FATNESS, CARDIORESPIRATORY FITNESS, METABOLIC RISK FACTORS

Vitamin D is a group of fat-soluble secosteriods responsible for the intestinal absorption of calcium and phosphate from the gut into the bloodstream, contributing to improved bone health (21). Serum vitamin D deficiency increases the risks of osteoporosis and osteomalacia in adults as well as the risk of rickets in children. More than 30 different types of cells within the body contain vitamin D receptors, including skeletal muscle, adipose tissue, and cardiac muscle (19). Accordingly, serum vitamin D insufficiency is related to the increased risk of metabolic syndrome, cardiovascular diseases, diabetes mellitus, cancers, infections, and autoimmune disease (17,18,22,23,27,31,39,46).

Sunlight exposure, diet, and supplements are three well-known determinants of serum vitamin D status. The majority of the vitamin D in our body is produced by cutaneous synthesis in response to sunlight exposure. Koreans are leading increasingly sedentary lifestyles with more time spent indoors and thus are not getting sufficient exposure to sunlight for adequate cutaneous production of vitamin D. Data from the 2008 and 2009 Korean National Health and Nutrition Examination Survey (KNHANES) (11,29,44) showed that the prevalence of serum vitamin D insufficiency in Korea has exceeded those of western countries including the United States and Canada. Vitamin D insufficiency in Korea has reached epidemic proportions and become a major health concern, especially in young adults because of their indoor dominant lifestyle (33). In addition, the prevalence rates of osteoporosis in Korean population age ≥50 yr are 8.1% in men and 38.7% in women, and the prevalence rates linearly increase with age, peaking at 68.2% in the ≥65 yr population (30). On the basis

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of data from the KNHANES from 1998 to 2007, Lim et al. (34) reported that the age-adjusted prevalence rates of metabolic syndrome increased significantly from 24.9% in 1998, 29.2% in 2001, and 30.4% in 2005 to 31.3% in 2007.

A global epidemic of metabolic syndrome, as defined by the clustering of hyperinsulinemia, hyperlidemia, and hypertension,has been observed in children, adolescents, and adults (8,24,34,47). Although the exact etiology of metabolic syndrome is uncertain, lifestyle factors including body fatness, physical inactivity, and poor physical fitness are likely attributed to its development. Lifestyle factors, such as body fatness and physical inactivity, have previously been reported to be negatively associated to serum vitamin D levels (9,13,15,16,48). In addition, cardiorespiratory fitness (CRF) has been reported to be positively related to serum vitamin D levels in men (4,15), women (15,41), and in patients with moderate chronic kidney disease (45). However, those studies reporting the associations between serum vitamin D levels and lifestyle factors have been mostly limited to non-Asian populations.

There is a limited number of investigations that have examined the relationship between lifestyle factors such as body fatness and physical inactivity and serum vitamin D in Koreans (20,11,4). More studies are needed to delineate the etiology and health consequences of low serum vitamin D levels in Asian countries including Korea. This study examined the relationship between serum 25(OH)D levels and body fatness, CRF, and metabolic risk factors in young Korean adults.

METHODS

Subjects and blood samples. This study included 809 college male students who registered in "health and fitness lectures" at the study institute between 2007 and 2009. All volunteers underwent a comprehensive health and fitness screening at the study laboratory. The average rates for the screening were 91%, 94%, and 92% in 2007, 2008, and 2009, respectively. Subjects were apparently healthy; free of any diagnosed chronic diseases such as diabetes, hypertension, dyslipidemia, or thyroid disease; and not taking any medications affecting blood pressure (BP), glucose, or lipid levels or related to body weight change. The Institutional Research Ethnics Review Committee reviewed and approved the study. After receiving written informed consent from each participant, a clinical evaluation was performed.

The clinical examinations included anthropometry and body composition, resting BP, fasting blood chemistry, and a maximal graded exercise test on a motor-driven treadmill. Height and body mass were recorded using a stadiometer attached to a scale (Jenix, Seoul, Korea). Waist circumference (WC) was measured using a cloth tape and was taken at the midpoint between the xiphoid process and the umbilicus. Percent body fat was assessed using bioelectrical impedance analysis following the procedures recommended by the American College of Sports Medicine (ACSM) (3).

BP was measured using an automated BP instrument (Jawon Medical Co., Kyungsan, South Korea). Subjects were instructed to refrain from using alcohol, smoking, and caffeine products and not to participate in any physical exercise within the last 24 h. Then subjects were reported to our laboratory after an overnight fast. On arrival, subjects had a 20-min rest in the supine position, followed by another 5 min in a seated position. Then, while remaining in the seated position, subjects were fitted with proper cuff sizes with the arm at heart levels, resting on the armrest of a chair. Two BP assessments were taken at 3-min intervals. The means of the two BPs were recorded.

Venous blood samples were drawn with the subjects in the supine position. Before blood sampling, the fasting state was verbally confirmed by the subject. Blood samples were taken from an antecubital vein of a forearm, immediately placed on ice, and centrifuged on site. Blood samples were stored at −70°C until biochemical assays for blood lipids, glucose, and insulin. Fasting glucose, total cholesterol (TC), triacylglycerols (TAG), and high-density lipoprotein cholesterol (HDLC) levels were measured in duplicate using an Ektachem DT-60 II analyzer (Johnson & Johnson Clinical Diagnostics, Inc., Rochester, NY). Fasting insulin was measured in duplicate using an enzyme-linked immunosorbent assay kit (ALPCO Diagnostics, Salem, NH). The index of insulin resistance was assessed using the homoeostasis model of assessment for insulin resistance (HOMA-IR), as HOMA-IR = [fasting insulin ($\mu U \cdot ml^{-1}$) × fasting glucose (mM)]/22.5. The intra- and interassay coefficients of variation for insulin were 2%–5% and 5%–9%, respectively.

Serum vitamin D levels were determined using the LIAISON 25(OH) vitamin D total assay (CLIA), which is a direct competitive chemiluminescence immunoassay for human serum or plasma intended for use on the DiaSorin LIAISON automated analyzer (DiaSorin S.P.A, Italy). The intra- and interassay coefficients of variation for 25-hydroxyvitamin D (25(OH)D) were 3%–6% and 7%–11%, respectively.

Determination of CRF. This was measured on a motor-driven treadmill according to the ACSM guidelines (3). The following criteria were used to confirm $\dot{V}O_{2max}$ achievement; (i) a leveling off of the $\dot{V}O_2$, (ii) RPE > 17 for the original category scale, (iii) volitional exertion, and (iv) achievement of age-predicted HR_{max}. Students were encouraged to exercise to exhaustion during the test. Individuals with a self-reported history of cardiovascular diseases such as diabetes, heart attacks, stroke, and/or cancer were excluded (n = 3). In addition, individuals who did not complete either the maximal treadmill test (n = 2) or measurements of metabolic syndrome markers including blood pressures, lipids, glucose, and insulin (n = 5) were excluded. Consequently, data obtained from 799 of the initial 809 participants were included in the data analyses.

Calculation of a clustered metabolic risk score. The study population consisted of young and healthy college male students with no evident pathologies and low prevalence of metabolic syndrome (i.e., overall 2.7%). In view of this

difficulty, a clustered metabolic risk score based on the National Cholesterol Education Program (NCEP-ATP III) criteria (14) was computed by summing standardized (z) scores for WC, resting BP (systolic BP [SBP] + diastolic BP [DBP]/2), TAG, the inverse of HDLC, glucose, and insulin. A z-score was computed from the sample mean after normalization of the variables (8,48). The computed risk scores are continuous variables with a mean of zero by definition, with lower scores denoting a more favorable profile and higher values indicating a less favorable profile in relation to the sample studied.

Statistical analyses. All variables were checked for normality and, if necessary, subjected to $\log_{10}$ transformation before statistical analyses. Descriptive statistics for raw variables across incremental serum vitamin D categories are presented as means ± SDs. In the present analyses, <12.5 ng·mL^{-1}, ≥12.5 ~ <20 ng·mL^{-1}, and ≥20 ng·mL^{-1} of serum vitamin D levels were classified as deficient, insufficient, and sufficient, respectively (25).

Tests for linear trends were performed with the Kruskal-Wallis test (two-tailed) for the median value for each category of serum vitamin D levels. Spearman coefficients of correlation were calculated among serum vitamin D levels, lifestyle factors such as body fatness and CRF, and metabolic risk factors. Coefficients of partial correlation were calculated between serum vitamin D and metabolic risk factors, controlling for age, smoking, and CRF and body fatness parameters in order. A generalized linear regression model was used to test a linear trend in the clustered metabolic risk score across incremental serum vitamin D categories, controlling for age, smoking, CRF, body mass index (BMI), and percent body fat.

In addition, participants were classified as unfit or fit based on the lowest 20% and remaining 80% of the age-standardized CRF distribution of $\dot{V}O_{2max}$ values in this study population. Serum 25(OH)D levels were categorized as <16 ng·mL^{-1} (inadequacy) and ≥16 ng·mL^{-1} (adequacy), which covers the requirements of approximately half the population in the United States and Canada (25). Unconditional binominal logistic regression was used to determine the odds ratios (ORs) and 95% confidence interval (95% CI) for having serum vitamin D inadequacy according to CRF levels, before and after adjusting for age, smoking, and body fatness parameters such as BMI, percent body fat, and WC. The fit group was used as the reference category (OR = 1.0). All P values are two-sided, and $P < 0.05$ was regarded as statistically significant. Statistical analyses were performed using SPSS-PC version 20.0 for Windows (Chicago, IL).

RESULTS

Table 1 shows the physical and biochemical characteristics of the study participants. There were linear decreases for body fatness parameters and a linear increase for CRF category across serum 25(OH)D levels. Linear decreases for metabolic risk factors including resting BPs, TAG, and insulin were found across incremental serum 25(OH)D categories. There was also a linear increase for HDLC across incremental serum 25(OH)D categories. No significant linear increases or decreases for age, TC, fasting glucose, HOMA-IR, and smoking rates were found across incremental serum 25(OH)D categories.

Table 2 shows the coefficients of partial correlation between serum 25(OH)D and measured parameters in this study population. Serum 25(OH)D was inversely related to BMI ($r = -0.295$, $P < 0.001$), percent body fat ($r = -0.333$, $P < 0.001$), WC ($r = -0.274$, $P < 0.001$), SBP ($r = -0.175$, $P < 0.001$), DBP ($r = -0.176$, $P = 0.001$), TC ($r = -0.162$, $P = 0.008$), TAG ($r = -0.253$, $P < 0.001$), and fasting insulin ($r = -0.203$, $P < 0.001$) and was positively related to CRF (r = 0.400, $P < 0.001$) and HDLC ($r = 0.208$, $P = 0.001$). After adjusting for age and smoking, serum 25(OH)D remained significantly correlated with SBP ($r = -0.190$, $P = 0.003$), DBP ($r = -0.135$, $P = 0.034$), TC ($r = -0.166$, $P = 0.009$), TAG ($r = -0.216$, $P = 0.001$), and HDLC ($r = 0.199$, $P = 0.002$). Serum 25(OH)D remained significantly correlated with SBP ($r = -0.128$, $P = 0.047$), TAG

TABLE 1. Description of study participants (mean ± SD).

	Deficient, <12.5 ng·mL^{-1} (n = 325)	Insufficient, ≥12.5 to <20 ng·mL^{-1} (n = 396)	Sufficient, ≥20 ng·mL^{-1} (n = 78)	P for Linear Trends
Age (yr)	24.2 ± 2.6	24.2 ± 2.2	23.7 ± 2.9	0.132
BMI (kg·m^{-2})	23.4 ± 3.4	22.1 ± 2.8	20.5 ± 2.1	<0.001
Body fat (%)	20.1 ± 5.7	17.7 ± 5.1	14.5 ± 4.2	<0.001
WC (cm)	82.8 ± 8.4	79.7 ± 7.8	75.7 ± 5.4	<0.001
CRF (mL·kg^{-1}·min^{-1})	40.5 ± 7.3	46.9 ± 6.3	49.5 ± 5.4	<0.001
SBP (mm Hg)	121.5 ± 12.0	118.9 ± 11.1	115.7 ± 11.0	<0.001
DBP (mm Hg)	71.6 ± 8.7	68.9 ± 7.2	67.7 ± 7.8	<0.001
TC (mg·dL^{-1})	174.6 ± 30.4	171.5 ± 30.1	161.7 ± 30.5	0.073
TAG (mg·dL^{-1})	113.8 ± 60.9	101.7 ± 48.7	88.1 ± 38.4	0.004
HDLC (mg·dL^{-1})	42.1 ± 8.4	44.1 ± 11.3	49.5 ± 15.3	0.015
FBG (mg·dL^{-1})	96.7 ± 9.6	95.4 ± 10.5	97.1 ± 11.7	0.402
Insulin (μU·mL^{-1})	7.93 ± 6.10	6.07 ± 4.23	5.23 ± 3.28	<0.001
HOMA-IR	1.86 ± 1.93	1.40 ± 1.15	1.27 ± 0.89	0.370
Nonsmoker/ smoker (%)	59.3/49.3	58.9/41.1	57.4/42.6	0.911

CRF was measured as the maximum volume of minute oxygen consumption ($\dot{V}O_{2max}$) during a graded treadmill test.
BMI, body mass index; CRF, cardiorespiratory fitness; DBP, diastolic blood pressure; FBG, fasting blood glucose; HDLC, high-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; SBP, systolic blood pressure; TAG, triacylglycerols; TC, total cholesterol; WC, waist circumference.

TABLE 2. Coefficients of correlation between 25-(OH)D and metabolic risk factors in the study population, before and after adjusting for lifestyle factors (n = 799).

	Unadjusted		Adjusted[a]		Adjusted[b]	
Parameter	r	P	r	P	r	P
BMI	−0.295	<0.001				
Body fat	−0.333	<0.001				
WC	−0.274	<0.001				
CRF	0.400	<0.001				
SBP	−0.175	<0.001	−0.190	0.003	−0.128	0.047
DBP	−0.176	0.001	−0.135	0.034	−0.087	0.179
TC	−0.162	0.008	−0.166	0.009	−0.095	−0.142
TAG	−0.253	<0.001	−0.216	0.001	−0.141	0.029
HDLC	0.208	0.001	0.199	0.002	0.150	0.012
FBG	−0.057	0.349	−0.066	0.300	−0.048	0.401
Insulin	−0.203	<0.001	−0.110	0.082	−0.073	0.262
HOMA-IR	−0.050	0.434	−0.097	0.129	−0.066	0.306

Spearman correlations were used to calculate coefficients of correlation among serum vitamin D, body fatness, CRF, and metabolic risk factors.
[a]Statistical analysis was conducted by using partial correlation, adjusted for age and smoking.
[b]Statistical analysis was conducted by using partial correlation, adjusted for age, smoking, CRF, and body fatness parameters.
BMI, body mass index; CRF, cardiorespiratory fitness; DBP, diastolic blood pressure; FBG, fasting blood glucose; HDLC, high-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; SBP, systolic blood pressure; TAG, triacylglycerols; TC, total cholesterol; WC, waist circumference.

(r = −0.141, P = 0.029), and HDLC (r = 0.150, P = 0.012) even after additionally adjusting for CRF and body fatness parameters including BMI, percent body fat, and WC. In addition, a linear decrease for the clustered metabolic risk score was found across incremental serum 25(OH)D categories (Fig. 1).

Table 3 shows the ORs with 95% CIs for serum vitamin D inadequacy, defined as having a serum 25(OH)D level <16 ng·mL^{-1}. Using $\dot{V}O_{2max}$ as the CRF exposure, unfit men were significantly more likely to have serum 25(OH)D inadequacy than fit men (reference). Adjustment for age and smoking had little effect on the strength of the association between CRF and serum 25(OH)D inadequacy. The OR of serum 25(OH)D inadequacy according to CRF levels remained significant when additionally adjusted for body fatness parameters including BMI, percent body fat, and WC.

DISCUSSION

This study examined the relationships of serum 25(OH)D levels to body fatness and fitness as well as metabolic risk factors in young adults in Korea. To our knowledge, this is the first study reporting significant associations between serum 25(OH)D levels, body fatness and fitness, and the clustering of metabolic risk factors in young men in Korea. Significant inverse trends for SBP and TAG were observed across incremental serum 25(OH)D categories, while a significant positive trend for HDLC was observed across incremental serum 25(OH)D categories, independent of age, smoking, CRF, and body fatness parameters. In particular, serum 25(OH)D levels were inversely associated with a clustered metabolic risk score, using the metabolic syndrome components as continuous variables. Consequently, the overall findings of the study suggest that while lifestyle factors such as body fatness and CRF are significant confounders to the relationships between serum 25(OH)D levels and metabolic risk factors, serum 25(OH)D inadequacy itself may also contribute to the clustering of metabolic risk factors, at least in this study population.

Our findings of high body fatness and low CRF being associated with low vitamin D levels are consistent with those of previous studies (2,11,12). Few data have been available on the relationship between serum 25(OH)D levels and lifestyle factors including body fatness and fitness, especially in Asian populations. Ardestani et al. (4) examined the association between serum 25(OH)D levels and CRF in 200 healthy adults participating in a double-blind clinical trial investigating statins and muscle performance (STOMP study). There was a significant association between serum 25(OH)D and CRF, even after adjusting for age, gender, and BMI. Using data obtained from the Cooper Center Longitudinal Study (CCLS), an updated version of the Aerobics Center Longitudinal Study (ACLS), Farrell et al. (15) and Farrell and Willis (16) found that serum 25(OH)D status was inversely related to body fatness and positively related to CRF in both men and women. In addition, data from the KNHANES IV (32) showed that serum

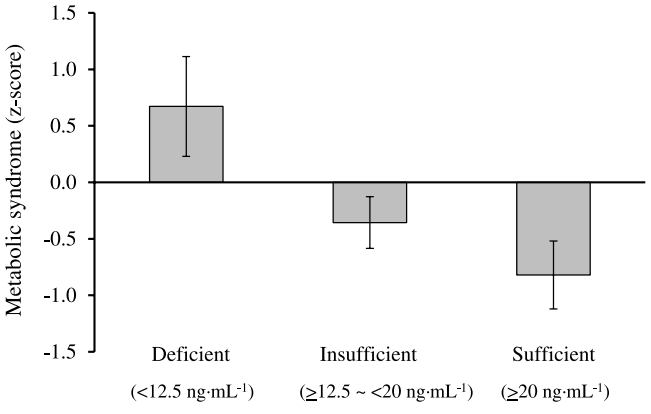

FIGURE 1—Relationship between serum vitamin D status and a sum of z-scores for the metabolic syndrome risk factors (P value for linear trend = 0.001, after adjusting for age, smoking, $\dot{V}O_{2max}$, body mass index, and percent body fat).

TABLE 3. OR (95% CI) of serum 25(OH)D inadequacy according to CRF levels (n = 799).

	OR (95% CI)	P	OR[a] (95% CI)	P	OR[b] (95% CI)	P
CRF						
Fit	1.000		1.000		1.000	
Unfit	2.516 (1.665–3.801)	<0.001	2.447 (1.606–3.727)	<0.001	1.721 (1.095–2.704)	0.018

CRF was measured as the maximum volume of minute oxygen consumption ($\dot{V}O_{2max}$) during a graded treadmill test.
[a]OR was adjusted for age and smoking.
[b]OR was adjusted for age, smoking, and body fatness parameters including BMI, percent body fat, and waist circumference.
BMI, body mass index; CI, confidence interval; CRF, cardiorespiratory fitness; OR, odds ratio.

25(OH)D levels were inversely related to whole-body dual-energy X-ray absorptiometry (DXA)–based body fat mass and were positively related to DXA-based lean body mass in Korean men only. However, no such associations were found in women, suggesting a possibility of sex-specific associations between serum vitamin D levels and body composition in Korean adults.

Several explanations can be given for these findings. First, body fatness has been consistently related to low serum 25(OH)D levels because of sequestration in fat (52), increased clearance by a larger body fat pool (42), negative feedback from higher circulating 1,25(OH)2D levels in obesity (5), and decreased sunlight exposure because of limited mobility or avoidance of outdoor activity (12). Thus, it seems reasonable to speculate that serum vitamin D insufficiency partially reflects the increased risk of body fatness associated with metabolic syndrome.

Second, CRF may contribute to the preventive effect(s) of serum vitamin D against metabolic syndrome. In an agreement, the logistic regression analyses showed that unfit men had a significantly higher risk for serum 25(OH)D inadequacy than unfit men (OR = 1.721, 95% CI = 1.095–2.704), even after adjusting for age, smoking, and body fatness parameters. The findings of the present study were in agreement with data from the STOMP and CCLS in which serum 25(OH)D levels were positively related to CRF and inversely related to body fatness in adults (2,11,12). While the nature of these cross-sectional observations does not prove or disprove causality, these trends suggest the possibility that CRF may affect serum 25(OH)D levels, or vice versa. CRF is determined primarily by maximal cardiac output and maximal arteriovenous O_2 difference. A recent study showed that 1,25(OH)2D might inhibit the cell cycle in the heart and restrict mechanisms causing myocardial fibrosis, improving myocardial structure or contractility in rats and mice (42).

Third, individual variations in daily sunlight exposure cannot be ruled out as a potential explanation for the association between serum 25(OH)D levels and CRF. Although primarily influenced by individual differences in genetic makeup, CRF is a set of physiological attributes that are also substantially enhanced through participation in regular physical activity (7). Consequently, CRF levels may reflect individual variations in sunlight exposure while participating in outdoor physical activities including exercise (35,48,49).

Finally, serum vitamin D insufficiency/deficiency is associated with insulin resistance, a key feature underlying metabolic syndrome (35,40). In agreement, Alvarez et al. (2) found that serum 25(OH)D was an independent predictor of whole-body insulin sensitivity index assessed by the intravenous glucose tolerance test in African American women. Chiu et al. (10) determined insulin sensitivity index and first and second phases of insulin secretion using the hyperglycemic clamp in a cohort of glucose-tolerant multiethnic young adults. In that study, serum 25(OH)D was positively associated with insulin sensitivity index and negatively associated with first- and second-phase insulin secretion. Kayaniyil et al. (28) examined the associations between serum 25(OH)D levels and insulin resistance index and β-cell dysfunction in 721 subjects at risk for type 2 diabetes. Using linear regression analyses, they found that serum 25(OH)D was independently associated with insulin sensitivity index for oral glucose tolerance tests and homeostasis model assessment of insulin resistance as well as β-cell function. Consequently, the protective effects of vitamin D against metabolic syndrome may be due to the effects of vitamin D on glucose homeostasis through several potential mechanisms, including increased biosynthesis (6) and secretion (26) of insulin from pancreatic β cells, enhanced insulin sensitivity in peripheral tissues (51), and the presence of a vitamin D response element in the human insulin receptor gene promoter (37). Further, 1,25(OH)2D stimulates transcription of the human insulin receptor gene (38) and stimulates insulin-mediated glucose transport in vitro (36). Vitamin D inhibits the renin–angiotensin system, and overactivity in this system in islets is reduced by activated vitamin D. Inhibition of the renin–angiotensin system prevents increases in blood pressure and controls T helper cells that inhibit inflammation, atherosclerosis, thrombosis, and vascular calcification, ultimately preventing the development of cardiovascular diseases (22).

Lack of information regarding sunlight exposure, indoor or outdoor exercise patterns, dietary vitamin D and calcium, and parathyroid hormone are some of the limitations of our data. Future research on the independent role of exercise, as well as the combined effects of exercise and dietary intake, on vitamin D bioavailability and metabolism is needed. Further, randomized and controlled trials are necessary to determine whether there is a causal relationship between serum vitamin D and body fatness, CRF, and metabolic risk factors.

In conclusion, serum vitamin D levels were inversely related to body fatness and a clustering of metabolic risk factors and were positively related to CRF in this study sample. The findings of this study suggest that increasing

vitamin D intake, eating a healthy diet, and getting enough outdoor physical activity should be major targets of lifestyle interventions against metabolic syndrome in young adults in Korea.

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