# Vitamin D Insufficiency in Korea—A Greater Threat to Younger Generation: The Korea National Health and Nutrition Examination Survey (KNHANES) 2008

Han Seok Choi, Han Jin Oh, Hoon Choi, Woong Hwan Choi, Jung Gu Kim, Kyoung Min Kim, Kwang Joon Kim, Yumie Rhee, and Sung-Kil Lim

Division of Endocrinology and Metabolism, Department of Internal Medicine (H.S.C.), Dongguk University Ilsan Hospital, Goyang-shi, Gyeonggi-do 410-773, Korea; Department of Family Medicine, College of Medicine (H.J.O.), Kwandong University, Gangneung 210-701, Korea; Department of Obstetrics and Gynecology, College of Medicine (H.C.), Inje University Sanggye Paik Hospital, Seoul 139-707, Korea; Division of Endocrinology and Metabolism, Department of Internal Medicine (W.H.C.), Hanyang University College of Medicine, Seoul 133-791, Korea; Department of Obstetrics and Gynecology, College of Medicine (J.G.K.), Seoul National University, Seoul 151-742, Korea; and Division of Endocrinology, Department of Internal Medicine (K.M.K., K.J.K., Y.R., S.-K.L.), Institute of Endocrine Research (H.S.C., K.M.K., K.J.K., Y.R., S.-K.L.), and Brain Korea 21 Project for Medical Sciences (S.-K.L.), Yonsei University College of Medicine, Seoul 120-752, Korea

**Context:** Vitamin D status in the Korean population has not been adequately determined.

**Objective:** To investigate the vitamin D status and the prevalence of vitamin D insufficiency in the Korean population, and also identify the predictors for vitamin D insufficiency in Korea.

**Design and Setting:** The Fourth Korea National Health and Nutrition Examination Surveys (KNHANES IV) in the Korean population conducted in 2008.

**Participants:** 3,047 males and 3,878 females aged 10 years and older selected in all the 16 administrative districts of South Korea.

**Main Outcome Measures:** Serum 25-hydroxyvitamin D [25(OH)D] levels and the prevalence of vitamin D insufficiency defined as serum 25(OH)D level of less than 20 ng/ml.

**Results:** Vitamin D insufficiency was found in 47.3% of males and 64.5% of females, whereas only 13.2% of male and 6.7% of female population had a serum 25(OH)D level of greater than 30 ng/ml. Vitamin D insufficiency was most prevalent in the age of 20–29, with a rate of 65.0% in males and 79.9% in females, and least prevalent in the age of 60–69 in males and 50–59 in females. Those who work usually indoors were more predisposed to vitamin D insufficiency. In the adult population, predictors for vitamin D insufficiency included young age groups, spring and winter seasons, living in an urban area, and indoor occupations.

**Conclusions:** Vitamin D insufficiency is very common, and it is now a greater threat to the younger generation in Korea. Current recommendations for vitamin D intakes for Koreans are inadequate, especially for the youth. **(*J Clin Endocrinol Metab* 96: 643–651, 2011)**

It has long been known that vitamin D plays an important role in bone and mineral metabolism with its deficiency being closely associated with the occurrence of metabolic bone disease such as rickets in children and osteomalacia in adults. Recently, vitamin D is also drawing interest of medical researchers with its wide variety of nonskeletal actions on cellular proliferation and differentiation, muscle function, and immunity (1). Vitamin D receptors have

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Abbreviations: 25(OH)D, 25-Hydroxyvitamin D; BMI, body mass index; DRI, dietary reference intake; KNHANES, Korea National Health and Nutrition Examination Surveys; NHANES, National Health and Nutrition Examination Survey.

been discovered in most cells and tissues throughout the body, and some of them also have the enzyme, 25-hydroxyvitamin D-1α-hydroxylase, which converts the primary form of vitamin D to the active form (1, 2). Previous studies have shown that vitamin D deficiency or insufficiency is associated with an increase in the risk of several health conditions including cardiovascular diseases (3–5), diabetes mellitus (6, 7), cancers (8–11), infection (12–14), and autoimmune diseases (15). It was also reported that vitamin D supplementation may reduce the risk of these diseases (16–19).

As more and more people live in the cities spending a majority of their time indoors, people can hardly get enough sunlight exposure for adequate cutaneous production of vitamin D. Thus, vitamin D insufficiency has become a major health concern in modern society. In a recent study performed in 7441 postmenopausal osteoporotic women from 29 countries participating in a clinical trial on bazedoxifene, the prevalence of 25-hydroxyvitamin D [25(OH)D] less than 20 ng/ml was as much as 35.3% in winter and 25.2% in summer, while the prevalence of 25(OH)D of 30 ng/ml or greater was 21.2% in winter and 27.5% in summer (20). In another study based on the data of National Health and Nutrition Examination Survey (NHANES) in the U.S. population, Ginde *et al.* compared serum 25(OH)D levels from NHANES III, collected during 1988 through 1994, with NHANES data collected from 2001 through 2004 (NHANES 2001–2004), and found a marked decrease in serum 25(OH)D levels from the 1988–1994 to the 2001–2004 data collections (21). The prevalence of serum 25(OH)D levels of less than 10 ng/ml increased from 2% in NHANES III to 6% in NHANES 2001–2004, while the prevalence of serum 25(OH)D levels of 30 ng/ml or greater decreased from 45% in NHANES III to 23% in NHANES 2001–2004 (21). In Korea, vitamin D insufficiency is also very common. In an international epidemiologic study that investigated the vitamin D status among postmenopausal osteoporotic women including 101 Korean, the mean serum 25(OH)D level of Korean participants was 17.6 ng/ml, which was the lowest among 18 countries, and the prevalence of 25(OH)D less than 30 ng/ml was the highest in Korea with a rate of 92.1% (22). However, the vitamin D status in the general population of Korea has not been adequately determined.

In this study, we investigated the vitamin D status and the prevalence of vitamin D insufficiency in the Korean population based on the Fourth Korea National Health and Nutrition Examination Surveys (KNHANES IV) conducted in 2008, and also identified the predictors for vitamin D insufficiency in Korea. This is the first nationwide epidemiologic study for vitamin D status in Korea.

## Subjects and Methods

### Study participants

This study is based on the data acquired in the second year (2008) of KNHANES IV. The KNHANES has been conducted periodically since 1998 to assess the health and nutritional status of the civilian noninstitutionalized population of the Korea (23). The KNHANES IV was a cross-sectional and nationally representative survey conducted by the Division of Chronic Disease Surveillance, Korea Centers for Disease Control and Prevention, from 2007 to 2009. The survey consists of a health interview survey, a nutrition survey, and a health examination survey. The survey collected data via household interviews and by direct standardized physical examinations conducted in specially equipped mobile examination centers. The sampling frame was based on the 2005 population and housing census in Korea. A stratified, multistage probability sampling design was used for the selection of household units. In the second year (2008) of the KNHANES IV, there were 264,186 primary sampling units, each of which contained ≈60 households. Two hundred sampling frames from primary sampling units were randomly sampled, and 23 households from each sampling frame (≈60 households) were sampled using a systemic sampling method. Finally, 12,528 individuals in 4,600 households were sampled, and 9,308 of them participated in health interviews and health examination surveys, and 8,641 participated in nutrition surveys. Among those who participated in the survey between February 2008 and December 2008, serum 25(OH)D levels were obtained for the investigation of vitamin D status in Korea. Serum 25(OH)D levels were obtained in 3,047 males and 3,878 females aged 10 yr and older from all 16 administrative districts of South Korea (Supplemental Table 1 and Supplemental Fig. 1, published on The Endocrine Society's Journals Online web site at http://jcem.endojournals.org/). All the participants in this survey signed an informed consent form.

### Measurement of serum 25(OH)D

For measurements of serum 25(OH)D levels, blood samples of individual subjects were collected during the survey. Blood samples were properly processed, immediately refrigerated, and transported in cold storage to the Central Testing Institute in Seoul, Korea. Blood samples were analyzed within 24 h after transportation. Serum 25(OH)D levels were measured using a $\gamma$ counter (1470 Wizard, Perkin-Elmer Finland) with a RIA (DiaSorin, Still Water, MN). The interassay coefficients of variation were 11.7%, 10.5%, 8.6%, and 12.5% at 8.6, 22.7, 33.0, and 49.0 ng/ml. We reported the proportion of participants with serum 25(OH)D level of less than 10, 10 to <20, 20 to <30, and 30 ng/ml or greater. Vitamin D insufficiency was defined as serum 25(OH)D level of less than 20 ng/ml.

### Statistical analyses

Statistical analyses were carried out using SAS V9.1 (SAS Institute, Cary, NC). For analyses of the relationship between possible predicting factors and vitamin D status, factors were categorized. Age was categorized by 10 yr to investigate the age-related change of serum 25(OH)D levels. Body mass index (BMI) were categorized as <23, 23 to <25, and ≥25 kg/m$^2$, which are the cut-off points for normal (including underweight), overweight, and obesity for Asian populations. Seasons were categorized as spring (March to May), summer (June to August), fall

(September to November), and winter (February and December). Region was categorized as urban and rural. Among the 16 administrative districts where this survey was conducted, Seoul (the capital city of South Korea) and the surrounding metropolitan area (Gyeonggi), and six other metropolitan cities (Busan, Daegu, Incheon, Gwangju, Daejeon, and Ulsan) of South Korea were grouped as urban areas. The remainder of the regions (Gangwon, Chungbuk, Chungnam, Jeonbuk, Jeonnam, Gyeongbuk, Gyeongnam, and Jeju) were grouped as rural areas. Because almost all areas of South Korea are located between 33

**TABLE 1.** Baseline characteristics and serum 25(OH)D levels in the survey[a]

| | Male | Female |
|---|---|---|
| No. of total participants | 3,047 | 3,878 |
| No. of adult participants aged ≥ 20 yr | 2,504 | 3,417 |
| Age group, yr | | |
| 10–19 | 543 (17.8) | 461 (11.9) |
| 20–29 | 311 (10.2) | 438 (11.3) |
| 30–39 | 541 (17.8) | 718 (18.5) |
| 40–49 | 521 (17.1) | 658 (17.0) |
| 50–59 | 434 (14.2) | 570 (14.7) |
| 60–69 | 384 (12.6) | 560 (14.4) |
| 70–79 | 263 (8.6) | 375 (9.7) |
| ≥80 | 50 (1.6) | 98 (2.5) |
| BMI, kg/m$^2$ | | |
| <23 | 1,368 (44.9) | 2,047 (52.8) |
| 23 to <25 | 721 (23.7) | 780 (20.1) |
| ≥25 | 932 (30.6) | 1,027 (26.5) |
| Missing | 26 (0.9) | 24 (0.6) |
| Season | | |
| Spring | 821 (26.9) | 994 (25.6) |
| Summer | 897 (29.4) | 1188 (30.6) |
| Fall | 888 (29.1) | 1099 (28.3) |
| Winter | 441 (14.5) | 597 (15.4) |
| Regions[b] | | |
| Rural area | 1,108 (36.4) | 1,409 (36.3) |
| Urban area | 1,939 (63.6) | 2,469 (63.7) |
| Occupation[c] | | |
| Agriculture, forestry, and fishery | 309 (12.3) | 335 (9.8) |
| Manual labor | 217 (8.7) | 340 (10.0) |
| Engineering, assembling, and technical work | 491 (19.6) | 81 (2.4) |
| Sales and services | 290 (11.6) | 408 (11.9) |
| Administration, clerical work, and specialists | 597 (23.8) | 450 (13.2) |
| Students | 68 (2.7) | 99 (2.9) |
| N/A | 508 (20.3) | 1,689 (49.4) |
| Missing | 24 (1.0) | 15 (0.4) |
| Regular walking[c,d] | | |
| Yes | 1,272 (50.8) | 1,547 (45.3) |
| No | 1,215 (48.5) | 1,841 (53.9) |
| Missing | 17 (0.7) | 29 (0.8) |
| Regular exercise[c,e] | | |
| Yes | 729 (29.1) | 876 (25.6) |
| No | 1,761 (70.3) | 2,525 (73.9) |
| Missing | 14 (0.6) | 16 (0.5) |
| Serum 25(OH)D level, ng/ml | | |
| <10 | 144 (4.7) | 403 (10.4) |
| 10 to <20 | 1,298 (42.6) | 2,098 (54.1) |
| 20 to <30 | 1,202 (39.4) | 1,119 (28.9) |
| ≥30 | 403 (13.2) | 258 (6.7) |

To convert 25(OH)D to nanomoles per liter, multiply by 2.496. N/A, Not applicable.

[a] Values are presented as number (%) or mean (SD).

[b] Regions were grouped as rural (Gangwon, Chungbuk, Chungnam, Jeonbuk, Jeonnam, Gyeongbuk, Gyeongnam, and Jeju) and urban (Seoul, Gyeonggi, Busan, Daegu, Incheon, Gwangju, Daejeon, and Ulsan) area.

[c] Among adult participants aged ≥20 yr.

[d] Regular walking was indicated as 'yes' when the subject walks for more than 30 min at a time and more than five times per week.

[e] Regular exercise was indicated as 'yes' when the subject does moderate or severe exercise on a regular basis (for more than 30 min at a time and more than five times per week in case of moderate exercise; for more than 20 min at a time and more than three times per week in case of severe exercise).

degree N and 38 degree N of latitude, the latitude of the area was not considered as a predicting factor for vitamin D status in this study. In the adult population, occupation was classified into seven groups, A (agriculture, forestry, and fishery), B (manual labor), C (engineering, assembling, and technical work), D (sales, and service), E (administration, clerical work, and specialists), F (students), and G (not applicable) based on the presumption that each group has a different level of sunlight exposure. Unemployed state, housework, and other unclassifiable works were grouped as G. Regular walking was indicated as 'yes' when the subject walks for more than 30 min at a time and more than five times per week, regardless of indoor or outdoor walking. Regular exercise was indicated as 'yes' when the subject does moderate or severe exercise on a regular basis, regardless of indoor or outdoor exercise (for more than 30 min at a time and more than five times per week in case of moderate exercise such as swimming slow, tennis doubles, volleyball, badminton, table tennis, and carrying light stuffs; for more than 20 min at a time and more than three times a week in case of severe exercise such as running, climbing, cycling fast, swimming fast, football, basketball, jump rope, squash, tennis singles, and carrying heavy stuffs). To compare the mean serum 25(OH)D levels among the categories in each possible predicting factor, Student's *t* tests or ANOVA were used. Univariate logistic regression analyses were used to evaluate the association between possible predicting factors and vitamin D insufficiency. Multivariate logistic regression analyses were also used to find the independent predictors for vitamin D deficiency. All tests are two-sided, and $P < 0.05$ was considered statistically significant.

## Results

The baseline characteristics and serum 25(OH) levels of subjects are presented in Table 1. The average age was 42.4 ± 19.6 yr with a range of 10–91 in males, and 45.0 ± 19.3 yr with a range of 10–93 in females.

### Serum 25(OH)D level and the prevalence of vitamin D insufficiency

The mean serum level of 25(OH)D was 21.2 ± 7.5 ng/ml in males and 18.2 ± 7.1 ng/ml in females. Vitamin D insufficiency was found in 47.3% of males and 64.5% of females, whereas only 13.2% of males and 6.7% of females had a serum 25(OH)D level of greater than 30 ng/ml (Table 1).

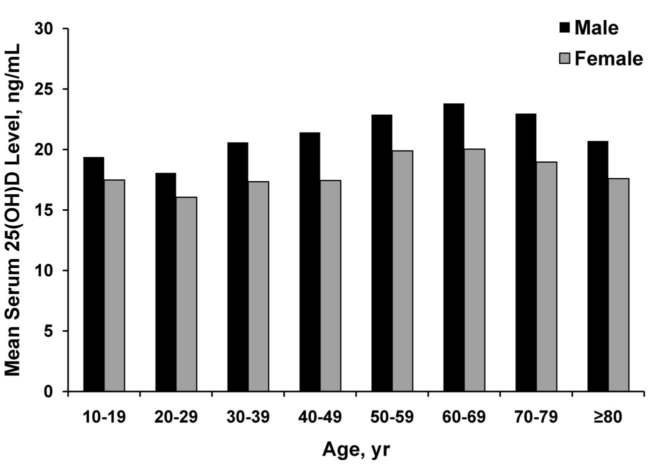


**FIG. 1.** Change of mean serum 25(OH)D levels stratified by 10-year age categories. To convert 25(OH)D levels to nanomoles per liter, multiply by 2.496.

The age-related change of serum 25(OH)D level in male and female is illustrated in Fig. 1 and Supplemental Fig. 2. From the ages of 10–19, mean serum 25(OH)D level decreased, reaching its lowest level at the age range of 20–29, then increased, reaching its peak at the age of 60–69, then decreased again in both sexes.

Figure 2 demonstrates the proportion of participants with serum 25(OH)D levels of less than 10, 10 to <20, 20 to <30, and 30 ng/ml or greater, stratified by 10-year age categories. In both sexes, the prevalence of vitamin D insufficiency increased from the age of 10–19, reaching its peak at the age of 20–29 (65.0% in male and 79.9% in female), and decreased, reaching its lowest levels at the age of 60–69 in male and 50–59 in female, then increased again. To exclude the effect of seasons, we also analyzed the prevalence of vitamin D insufficiency in each season, and could observe a similar pattern in each season (Supplemental Fig. 3).

In adult participants aged 20 yr or older, the prevalence of vitamin D insufficiency in various occupation groups is illustrated in Fig. 3. As expected, subjects in group A, who usually work outdoors and therefore have more chance of sunlight exposure, had the lowest rate of vitamin D insufficiency in both males (19.7%) and females (34.9%), whereas those who usually work indoors had a higher rate of vitamin D insufficiency. Interestingly, students also had very high rates of vitamin D insufficiency in both male (69.1%) and female (75.8%). In participants younger than 20 yr of age, the prevalence of vitamin D insufficiency by school they attend is presented in Supplemental Fig. 4. Participants in higher grades showed higher levels of vitamin D insufficiency.

### Predictors for vitamin D insufficiency in adults

We also conducted statistical analyses to find the predictors for vitamin D insufficiency in adults aged 20 yr or older. Possible predicting factors in our study included age, BMI, season, region, occupation, regular walking, and exercise. Table 2 displays the possible predicting factors for serum 25(OH)D levels and the mean serum 25(OH)D levels by different characteristics. ANOVA or Student *t* test showed that mean serum 25(OH)D levels are significantly different between the groups of all factors except for BMI in males.

Univariate logistic regression analyses were used to determine predictors associated with the prevalence of vitamin D insufficiency in adults (Supplemental Table 2). All the possible predicting factors except for BMI in males

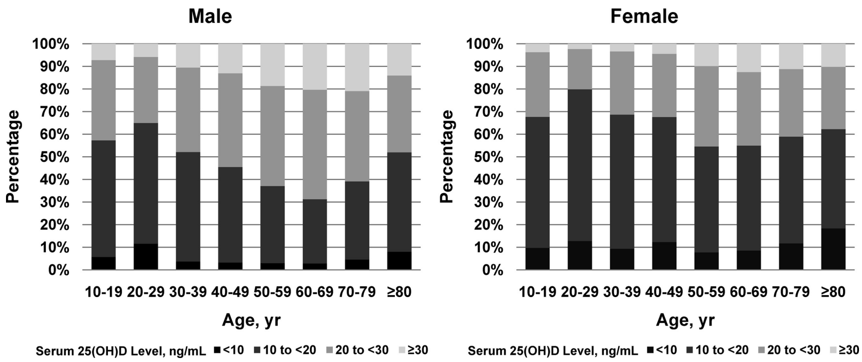


**FIG. 2.** The numbers of participants with serum 25(OH)D level of less than 10, 10 to <20, 20 to <30, and 30 ng/ml or greater stratified by 10-year age categories. To convert 25(OH)D levels to nanomoles per liter, multiply by 2.496.

were found to have statistically significant associations with vitamin D insufficiency. Fig. 4 shows the results of multivariate logistic regression analyses to determine independent predictors for vitamin D insufficiency in both sexes. In the multivariate logistic regression model including all the possible predicting factors in Table 2, age groups (20–29, 30–39, and 40–49), season (spring and winter), region (urban), occupations (B–G), and regular exercise (no) were found to be independent predictors for vitamin D insufficiency in both sexes. In addition, age group (≥80) was also an independent predictor in male, and BMI (<23) and regular walking (no) were independent predictors in female for vitamin D insufficiency.

## Discussion

Old age has been suggested as a risk factor for vitamin D insufficiency because the cutaneous synthesis of vitamin $D_3$ declines with age (1, 24, 25). It was reported that aging can decrease by >2-fold the capacity of the skin to produce previtamin $D_3$ in response to UV radiation (24). Unexpectedly, however, our results showed that the serum 25(OH)D level increases with age from 20–29 to 60–69 in both sexes, and vitamin D insufficiency was most prevalent in the age of 20–29. In statistical analyses to identify the predictors for vitamin D insufficiency in Korean adults, predictors for vitamin insufficiency included young age groups, spring and winter seasons, living in an urban area, and indoor occupations. Much to our regret, KNHANES did not include the questions about each subject's amount of sunlight exposure. Instead, we obtained the data regarding participants' occupation, which presumably reflects the each subject's amount of sunlight exposure. Those who work in agriculture, forestry, or fishery usually spend their working time outdoors, thereby having more exposure of sunlight than those who spend their working time indoors. As we expected, there were associations between occupation and vitamin D status. Those who usually work indoors were more predisposed to vitamin D insufficiency, while those who work outdoors have relatively higher serum levels of vitamin D. Further analyses of our data also revealed that there exists a clear difference in the kinds of jobs occupied by young and older generations (data not shown). Young adults tend to have indoor jobs, while elderly adults tend to have outdoor jobs. This phenomenon, which could also be observed in other industrialized countries, is related to the rapid economic development over the past three decades in Korea. As Korea's main industry has changed from agriculture and fishery to manufacturing and commerce, younger generations have moved to and settled in urban areas and acquired indoor jobs, whereas older generations have stayed in rural areas, working in agriculture, forestry, or fishery. This partially explains why the younger generation is at greater risk for vitamin D insufficiency than older generation in Korea. However, even after adjusting for other confounders, younger age groups were still independent predictors for vitamin D insufficiency in our study. Although the cause of this finding is not clear, it might be due to other behavioral factors that we did not adjust in the statistical analyses, which may include indoor lifestyle, sunscreen use, outdoor activity, or dietary habits. Another interesting result in our study is a very high prevalence of vitamin D insufficiency in students, especially those in

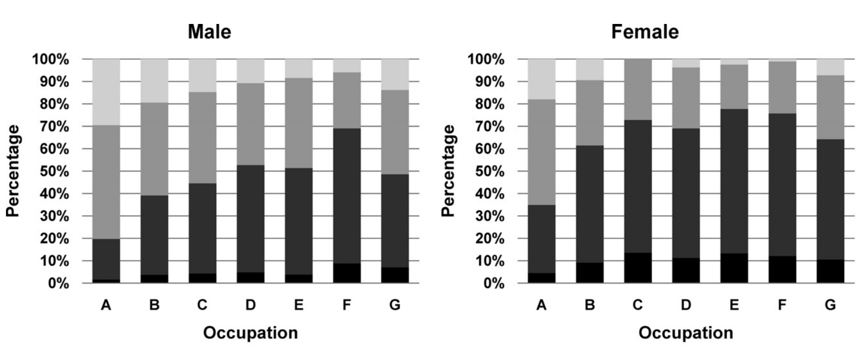


**FIG. 3.** The numbers of participants with serum 25(OH)D level of less than 10, 10 to <20, 20 to <30, and 30 ng/ml or greater divided by occupation groups in adults aged 20 yr or older. Occupation classification: A (agriculture, forestry, and fishery), B (manual labor), C (engineering, assembling, and technical work), D (sales, and service), E (administration, clerical work, and specialists), F (students), and G (not applicable). To convert 25(OH)D levels to nanomoles per liter, multiply by 2.496.

**TABLE 2.** Mean serum 25 (OH)D levels by participant characteristics in adults ($n$ = 5,921)[a]

| Factors | Male: Serum 25(OH)D Level, ng/ml | Male: P value[b] | Female: Serum 25(OH)D Level, ng/ml | Female: P value[b] |
|---|---|---|---|---|
| Age group, yr | | | | |
| 20–29 | 18.1 (7.0) | | 16.1 (5.7) | |
| 30–39 | 20.6 (7.3) | | 17.3 (6.2) | |
| 40–49 | 21.4 (7.0) | | 17.4 (6.5) | |
| 50–59 | 22.9 (7.6) | | 19.9 (7.5) | |
| 60–69 | 23.8 (7.5) | | 20.0 (7.9) | |
| 70–79 | 23.0 (8.3) | | 19.0 (8.0) | |
| ≥80 | 20.7 (8.1) | <0.001 | 17.6 (8.0) | <0.001 |
| BMI, kg/m² | | | | |
| <23 | 21.8 (8.1) | | 17.8 (7.2) | |
| 23 to <25 | 21.7 (7.6) | | 18.7 (7.1) | |
| ≥25 | 21.3 (7.0) | 0.259 | 18.8 (7.0) | <0.001 |
| Season | | | | |
| Spring | 17.8 (6.5) | | 14.8 (6.0) | |
| Summer | 24.4 (7.8) | | 20.3 (7.0) | |
| Autumn | 23.9 (7.0) | | 20.3 (7.1) | |
| Winter | 18.4 (6.0) | <0.001 | 16.1 (6.4) | <0.001 |
| Region[c] | | | | |
| Rural area | 23.8 (7.7) | | 19.9 (7.2) | |
| Urban area | 20.3 (7.3) | <0.001 | 17.3 (6.9) | <0.001 |
| Occupation | | | | |
| Agriculture, forestry, and fishery | 26.3 (7.3) | | 22.9 (7.2) | |
| Manual labor | 23.1 (8.0) | | 18.9 (7.3) | |
| Engineering, assembling, and technical work | 21.8 (7.3) | | 16.2 (5.8) | |
| Sales, and services | 20.2 (7.7) | | 17.3 (6.4) | |
| Administration, clerical work, and specialists | 20.1 (6.6) | | 16.0 (5.8) | |
| Students | 18.1 (6.6) | | 16.1 (6.0) | |
| N/A | 20.9 (8.0) | <0.001 | 18.3 (7.2) | <0.001 |
| Regular walking[d] | | | | |
| Yes | 22.1 (7.9) | | 18.9 (7.2) | |
| No | 21.0 (7.3) | <0.001 | 17.7 (7.0) | <0.001 |
| Regular exercise[e] | | | | |
| Yes | 23.2 (7.6) | | 19.5 (7.3) | |
| No | 20.9 (7.5) | <0.001 | 17.8 (7.0) | <0.001 |

To convert 25(OH)D to nanomoles per liter, multiply by 2.496. N/A, Not applicable.

[a] Values are presented as mean (SD).

[b] *P* values are for ANOVA or Student *t* test.

[c] Regions were grouped as rural (Gangwon, Chungbuk, Chungnam, Jeonbuk, Jeonnam, Gyeongbuk, Gyeongnam, and Jeju) and urban (Seoul, Gyeonggi, Busan, Daegu, Incheon, Gwangju, Daejeon, and Ulsan) area.

[d] Regular walking was indicated as 'yes' when the subject walks for more than 30 min at a time and more than five times per week.

[e] Regular exercise was indicated as 'yes' when the subject does moderate or severe exercise on a regular basis (for more than 30 min at a time and more than five times per week in case of moderate exercise; for more than 20 min at a time and more than three times per week in case of severe exercise).

high school or college. It is probable that these students may have similar sunlight exposure to indoor workers because they also spend much time in indoor places such as school or library.

Previously, higher prevalence of vitamin D insufficiency in younger age groups was also noted in the National Diet and Nutrition Survey (NDNS) 1992–2001 of the United Kingdom (26). The survey showed that vitamin D deficiency or insufficiency was most prevalent in young adults aged 19–24 yr as well as in the elderly over the age of 85 yr. The study by Ginde *et al.* (21) based on NHANES database in U.S. population, which compared serum 25(OH)D levels from NHANES III (1988–1994) with NHANES 2001–2004, also gives us some implications. In the NHANES III (1988–1994), there was a definite trend toward lower serum 25(OH)D levels with increasing age. However, in the NHANES 2001–2004 database, serum 25(OH)D levels were similar across the age spectrum. Previous differences of serum 25(OH)D levels by age equalized. They speculated that the loss of age-related dif-

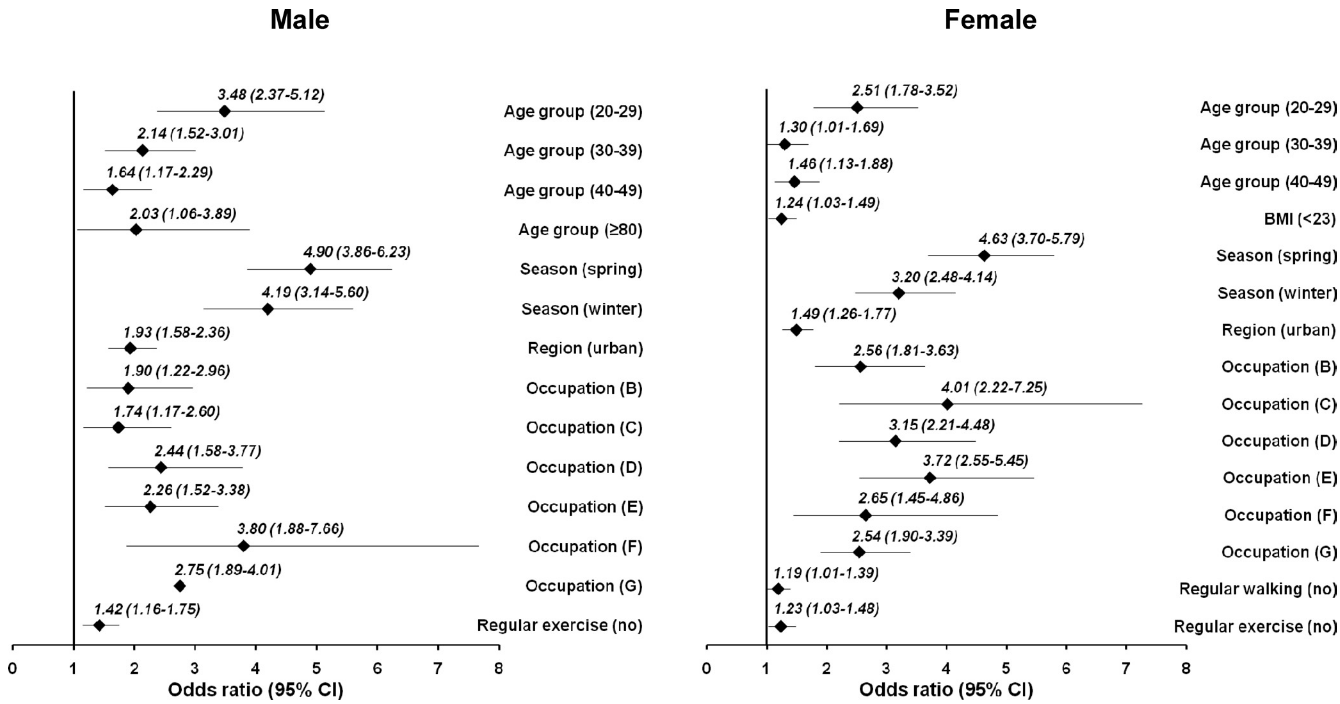


**FIG. 4.** Predictors independently associated with vitamin D insufficiency in adults aged 20 yr or older. References for each predictor: age group (60–69), season (summer), region (rural area), occupation (A), and regular exercise (yes) in male; age group (50–59), BMI (≥25), season (summer), region (rural area), occupation (A), regular walking (yes), and regular exercise (yes) in female. Occupation classification: A (agriculture, forestry, and fishery), B (manual labor), C (engineering, assembling, and technical work), D (sales, and service), E (administration, clerical work, and specialists), F (students), and G (not applicable).

ferences of serum 25(OH)D might be secondary to disproportionately greater time spent indoors and less time spent outdoors among younger compared with older individuals. Along with our study, these studies based on the NDNS of the United Kingdom and NHANES of the United States also imply that vitamin D insufficiency is not only a problem of older generations anymore but also an important health concern among younger generations.

The Food and Nutrition Board at the Institute of Medicine of The National Academies developed the dietary reference intakes (DRIs) for U.S. and Canadian populations in 1997. The DRIs of vitamin D, which are stratified by age, state that adequate intakes of vitamin D are 200 IU daily for young adults under 50, 400 IU daily for those aged between 51 and 70, and 600 IU daily for those aged over 70 (27). However, several scientists and research groups have suggested that new evidences demonstrate the need to revise the DRIs of vitamin D by increasing the reference values (27, 28). The National Osteoporosis Foundation currently recommends 400–800 IU of vitamin D daily for adults under 50 and 800-1000 IU of vitamin D daily for adults aged over 50. The Korean Nutrition Society also published the DRIs for Koreans in 2005 (29). The adequate intakes of vitamin D were established at 200 IU daily for young Korean adults, and 400 IU daily for adults aged over 50 yr. Based on the results of our study, however, we found that the current DRIs of vitamin D for Koreans are not enough to maintain sufficient serum 25(OH)D levels, especially for young adults. That is because daily intake of 400 IU vitamin D would raise serum 25(OH)D by only 3.6–5.6 ng/ml in healthy young adults (30), while it could raise the level by as much as 14–16 ng/ml in the elderly (31, 32). We also suggest that the current age stratification in recommendations for vitamin D intake may not be reasonable at least in Korea. Our results showed that young adults are now at greater risk for vitamin D insufficiency than the elderly. Thus, young adults may need vitamin D supplementation as much as or even more than that for the elderly. Also, occupation of each individual should be considered when we recommend vitamin D supplementation. Those who spend most of their time indoors may need more dosage of vitamin D supplements than those who spend their time outdoors.

The present study has some limitations. First, we did not inquire into each individual's amount of sunlight exposure. We only assumed that those who work outdoors would have more sunlight exposure, while those who work indoors would have less. Thus, we could not estimate how the level of sunlight exposure actually differs among the various occupations. Second, we did not obtain data regarding behavioral factors that could affect cutaneous synthesis of vitamin D such as sunscreen use or clothing. Third, we did not obtain data regarding each individual's vitamin D intake through diet and supplements, which might have affected the subject's vitamin D status to some extent. Fourth, serum 25(OH)D levels in January, which are presumed to be among the lowest in the 12-month cycle, were not included in this study. Therefore, it is probable that the prevalence of vitamin D insufficiency in the year was somewhat underestimated in our study.

In conclusion, we found that vitamin D insufficiency is a very common health problem in Korea. Our study also implies that vitamin D insufficiency is now a greater threat to younger generation. Further study is necessary to investigate whether this finding is a more recent worldwide trend in the modern epidemic of vitamin D insufficiency. As our results suggest, young people who live in urban areas working indoors are at greater risk of vitamin D insufficiency, especially in spring and winter. Based on our results, we suggest that current recommendations for vitamin D intakes are inadequate for Koreans, especially for the younger population, and that age stratification in recommendations for vitamin D intake may not be reasonable. Furthermore, occupation and other behavioral factors of each individual need to be considered in the recommendations for vitamin D intake.

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Address all correspondence and requests for reprints to: Sung-Kil Lim, M.D., Ph.D., Department of Internal Medicine, Yonsei University College of Medicine, 134 Sinchon-dong, Seodaemun-gu, Seoul 120-752, Korea. E-mail: lsk@yuhs.ac.

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## References


1. **Holick MF** 2007 Vitamin D deficiency. N Engl J Med 357:266–281
2. **DeLuca HF** 2004 Overview of general physiologic features and functions of vitamin D. Am J Clin Nutr 80:1689S–1696S
3. **Poole KE, Loveridge N, Barker PJ, Halsall DJ, Rose C, Reeve J, Warburton EA** 2006 Reduced vitamin D in acute stroke. Stroke 37:243–245
4. **Forman JP, Giovannucci E, Holmes MD, Bischoff-Ferrari HA, Tworoger SS, Willett WC, Curhan GC** 2007 Plasma 25-hydroxyvitamin D levels and risk of incident hypertension. Hypertension 49: 1063–1069
5. **Giovannucci E, Liu Y, Hollis BW, Rimm EB** 2008 25-hydroxyvitamin D and risk of myocardial infarction in men: a prospective study. Arch Intern Med 168:1174–1180
6. **Mattila C, Knekt P, Mannisto S, Rissanen H, Laaksonen MA, Montonen J, Reunanen A** 2007 Serum 25-hydroxyvitamin D concentration and subsequent risk of type 2 diabetes. Diabetes Care 30:2569–2570
7. **Pittas AG, Lau J, Hu FB, Dawson-Hughes B** 2007 The role of vitamin D and calcium in type 2 diabetes. A systematic review and meta-analysis. J Clin Endocrinol Metab 92:2017–2029
8. **Ahonen MH, Tenkanen L, Teppo L, Hakama M, Tuohimaa P** 2000 Prostate cancer risk and prediagnostic serum 25-hydroxyvitamin D levels (Finland). Cancer Causes Control 11:847–852
9. **Giovannucci E, Liu Y, Rimm EB, Hollis BW, Fuchs CS, Stampfer MJ, Willett WC** 2006 Prospective study of predictors of vitamin D status and cancer incidence and mortality in men. J Natl Cancer Inst 98:451–459
10. **Lin J, Manson JE, Lee IM, Cook NR, Buring JE, Zhang SM** 2007 Intakes of calcium and vitamin D and breast cancer risk in women. Arch Intern Med 167:1050–1059
11. **Jenab M, Bueno-de-Mesquita HB, Ferrari P, van Duijnhoven FJ, Norat T, Pischon T, Jansen EH, Slimani N, Byrnes G, Rinaldi S, Tjonneland A, Olsen A, Overvad K, Boutron-Ruault MC, Clavel-Chapelon F, Morois S, Kaaks R, Linseisen J, Boeing H, Bergmann MM, Trichopoulou A, Misirli G, Trichopoulos D, Berrino F, Vineis P, Panico S, Palli D, Tumino R, Ros MM, van Gils CH, Peeters PH, Brustad M, Lund E, Tormo MJ, Ardanaz E, Rodriguez L, Sanchez MJ, Dorronsoro M, Gonzalez CA, Hallmans G, Palmqvist R, Roddam A, Key TJ, Khaw KT, Autier P, Hainaut P, Riboli E** 2010 Association between pre-diagnostic circulating vitamin D concentration and risk of colorectal cancer in European populations:a nested case-control study. BMJ 340:b5500
12. **Wilkinson RJ, Llewelyn M, Toossi Z, Patel P, Pasvol G, Lalvani A, Wright D, Latif M, Davidson RN** 2000 Influence of vitamin D deficiency and vitamin D receptor polymorphisms on tuberculosis among Gujarati Asians in west London: a case-control study. Lancet 355:618–621
13. **Laaksi I, Ruohola JP, Tuohimaa P, Auvinen A, Haataja R, Pihlajamaki H, Ylikomi T** 2007 An association of serum vitamin D concentrations $<$ 40 nmol/L with acute respiratory tract infection in young Finnish men. Am J Clin Nutr 86:714–717
14. **Ginde AA, Mansbach JM, Camargo Jr CA** 2009 Association between serum 25-hydroxyvitamin D level and upper respiratory tract infection in the Third National Health and Nutrition Examination Survey. Arch Intern Med 169:384–390
15. **Kamen D, Aranow C** 2008 Vitamin D in systemic lupus erythematosus. Curr Opin Rheumatol 20:532–537
16. **Wang L, Manson JE, Song Y, Sesso HD** 2010 Systematic review: Vitamin D and calcium supplementation in prevention of cardiovascular events. Ann Intern Med 152:315–323
17. **Lappe JM, Travers-Gustafson D, Davies KM, Recker RR, Heaney RP** 2007 Vitamin D and calcium supplementation reduces cancer risk: results of a randomized trial. Am J Clin Nutr 85:1586–1591
18. **Avenell A, Cook JA, Maclennan GS, Macpherson GC** 2007 Vitamin D supplementation to prevent infections: a sub-study of a randomised placebo-controlled trial in older people (RECORD trial, ISRCTN 51647438). Age Ageing 36:574–577
19. **Urashima M, Segawa T, Okazaki M, Kurihara M, Wada Y, Ida H** 2010 Randomized trial of vitamin D supplementation to prevent seasonal influenza A in schoolchildren. Am J Clin Nutr 91:1255–1260
20. **Kuchuk NO, van Schoor NM, Pluijm SM, Chines A, Lips P** 2009 Vitamin D status, parathyroid function, bone turnover, and BMD in postmenopausal women with osteoporosis: global perspective. J Bone Miner Res 24:693–701
21. **Ginde AA, Liu MC, Camargo Jr CA** 2009 Demographic differences and trends of vitamin D insufficiency in the US population, 1988–2004. Arch Intern Med 169:626–632
22. **Lips P, Hosking D, Lippuner K, Norquist JM, Wehren L, Maalouf G, Ragi-Eis S, Chandler J** 2006 The prevalence of vitamin D inadequacy amongst women with osteoporosis: an international epidemiological investigation. J Intern Med 260:245–254
23. **Yoon YS, Oh SW, Baik HW, Park HS, Kim WY** 2004 Alcohol consumption and the metabolic syndrome in Korean adults: the 1998 Korean National Health and Nutrition Examination Survey. Am J Clin Nutr 80:217–224
24. **MacLaughlin J, Holick MF** 1985 Aging decreases the capacity of human skin to produce vitamin D3. J Clin Invest 76:1536–1538
25. **Mithal A, Wahl DA, Bonjour JP, Burckhardt P, Dawson-Hughes B, Eisman JA, El-Hajj Fuleihan G, Josse RG, Lips P, Morales-Torres J**

2009 Global vitamin D status and determinants of hypovitaminosis D. Osteoporos Int 20:1807–1820

26. **Prentice A** 2008 Vitamin D deficiency: a global perspective. Nutr Rev 66:S153–164
27. **Yetley EA, Brule D, Cheney MC, Davis CD, Esslinger KA, Fischer PW, Friedl KE, Greene-Finestone LS, Guenther PM, Klurfeld DM, L'Abbe MR, McMurry KY, Starke-Reed PE, Trumbo PR** 2009 Dietary reference intakes for vitamin D: justification for a review of the 1997 values. Am J Clin Nutr 89:719–727
28. **Bischoff-Ferrari HA, Giovannucci E, Willett WC, Dietrich T, Dawson-Hughes B** 2006 Estimation of optimal serum concentrations of 25-hydroxyvitamin D for multiple health outcomes. Am J Clin Nutr 84:18–28
29. **Paik HY** 2008 Dietary reference intakes for Koreans (KDRIs). Asia Pac J Clin Nutr 17(Suppl 2):416–419
30. **Barger-Lux MJ, Heaney RP, Dowell S, Chen TC, Holick MF** 1998 Vitamin D and its major metabolites: serum levels after graded oral dosing in healthy men. Osteoporos Int 8:222–230
31. **Lips P, Wiersinga A, van Ginkel FC, Jongen MJ, Netelenbos JC, Hackeng WH, Delmas PD, van der Vijgh WJ** 1988 The effect of vitamin D supplementation on vitamin D status and parathyroid function in elderly subjects. J Clin Endocrinol Metab 67:644–650
32. **Ooms ME, Roos JC, Bezemer PD, van der Vijgh WJ, Bouter LM, Lips P** 1995 Prevention of bone loss by vitamin D supplementation in elderly women: a randomized double-blind trial. J Clin Endocrinol Metab 80:1052–1058