J Nutr Sci Vitaminol, **66**, 508–514, 2020

Low Muscle Mass Is Associated with Lower 25-Hydroxyvitamin D Level in All Age Groups of South Korean Adults: The 2009–2010 Korea National Health and Nutrition Examination Surveys (KNHANES)

Dae-Geun Jang[1], So-Yeon Ryu[2], Jong Park[2] and Seong-Woo Choi[2,*]

[1] *Department of Public Health, Graduate School of Chosun University, 309, Pilmun-daero, Dong-gu, Gwangju 61452, Republic of Korea*
[2] *Department of Preventive Medicine, Chosun University Medical School, 309, Pilmun-daero, Dong-gu, Gwangju 61452, Republic of Korea*

(Received January 7, 2020)

Summary Vitamin D plays pivotal role in bone mineral homeostasis. But the association of vitamin D with muscle mass remains obscure, especially among young adults. Therefore, we assessed the association between muscle mass and 25-hydroxyvitamin D (25[OH]D) in South Korean adults using data from the 2009–2010 Korean National Health and Nutrition Examination Survey (KNHANES). This study involved 12,324 (5,375 males and 6,949 females) participants in the 2009–2010 KNHANES aged 20 y or older. Appendicular skeletal muscle mass (ASM) was measured by dual X-ray absorptiometry. Low muscle mass was defined as an ASM divided by body mass index (BMI) (ASM [kg]÷BMI [kg/m^2]) value of <0.789 in males and <0.512 in females. The vitamin D status was evaluated by assaying the serum 25(OH)D level. After adjustment for covariates, low muscle mass was significantly associated with lower 25(OH)D level (odds ratio [OR], 0.55; 95% confidence interval [CI], 0.40–0.75 for 10.0–19.9 ng/mL vs. <10.0 ng/mL; OR, 0.47; 95% CI, 0.33–0.68 for 20.0–29.9 ng/mL vs. <10.0 ng/mL; and OR, 0.39; 95% CI, 0.24–0.64 for ≥30.0 ng/mL vs. <10.0 ng/mL). Moreover, low muscle mass was significantly associated with lower 25(OH)D level in all age groups. In conclusion, low muscle mass was significantly associated with lower 25(OH)D level in South Korean adults in all age groups.

Key Words low muscle mass, 25-hydroxyvitamin D, sarcopenia, vitamin D, Korea

Muscle mass, a major component of tissue loss in sarcopenia, decreases with age, reducing exercise capacity and increasing the risk of falls and fractures in older adults (*1*). These changes also reduce the ability of seniors to perform daily activities, leading to a loss of independence and increasing the risk of death (*2*). Recognized the importance of muscle mass, decreased muscle mass were defined as sarcopenia in the elderly (*3*). Recently, the importance of muscle function and muscle strength has been emphasized, and reduced muscle function and muscle strength are included in the definition of sarcopenia as well as low muscle mass (*4*, *5*). However, the definition of sarcopenia still differs among researchers, and there are many studies that define sarcopenia simply by low muscle mass (*6*).

The prevalence of low muscle mass in the United States (US) is 7% in males and 10% in females over 60 y of age (*7*). The prevalence of low muscle mass in South Korean adults over 60 y of age is estimated to be 6.3% in males and 4.1% in females (*6*). However, direct comparison is hampered by the use of different diagnostic methods for low muscle mass.

Vitamin D, absorbed from fish, egg yolk, and vitamin D-enriched dairy products (*8*), is transported to the liver in association with vitamin D-binding protein (*9*). There, it is converted to 25-hydroxyvitamin D (25[OH]D) by a hydroxylase and subsequently to the biologically active 1,25-dihydroxycholecalciferol (1,25[OH]$_2$D$_3$) by hydroxylation in the kidneys (*9*). Vitamin D deficiency is associated with hypertension, diabetes, cardiovascular disease, and cancer (*10–12*), as well as bone diseases such as rickets in children and osteomalacia in adults (*13*). In addition, vitamin D is reported to be associated with muscle mass. This suggests that vitamin D deficiency affects the receptors for vitamin D in muscle cells, leading to decreased protein synthesis and muscle weakening (*14*). However, studies on this topic have yielded inconsistent results (*15–19*). Some found a correlation between a low vitamin D level and low muscle mass (*15*, *16*), some that the association differed depending on sex (*17*, *18*), and some reported no relationship between vitamin D and low muscle mass (*19*). In addition, low muscle mass is regarded as a problem of older people, so most studies focused on elderly populations. However, decreases in muscle mass and strength also occur in younger people.

South Koreans have the lowest vitamin D level of any nation, and the incidence of vitamin D deficiency is higher in younger than in older people (*20*). Therefore,

*To whom correspondence should be addressed.
E-mail: jcsw74@hanmail.net

an investigation of the relationship between vitamin D and muscle mass in all age groups is needed. We investigated the relationship between muscle mass and 25(OH) D level in South Korean adults using data from the 2009–2010 Korean National Health and Nutrition Examination Survey (KNHANES).

MATERIALS AND METHODS

Study population. This study used data from the 2009–2010 KNHANES. The KNHANES, a nationwide cross-sectional survey conducted annually by the Korea Centers for Disease Control and Prevention (KCDCP), consists of a health survey, health examination, and nutrition survey (*21*). KNHANES used a stratified, multistage, clustered probability sampling method to select a representative sample of noninstitutionalized, civilian Koreans. The health survey and nutrition survey are conducted by trained interviewers using questionnaires, and the health examinations are performed by trained medical staff. The KNHANES complies with all tenets of the Declaration of Helsinki and the KCDCP Ethics Committee approved the study protocol (2009-01CON-03-2C, 2010-02CON-21-C), and written informed consent was obtained from all subjects or their parents.

The number of participants in the KNHANES 2009–2010 was 19,491 (10,533 in 2009 and 8,958 in 2010), among whom, 17,729 were adults over 20 y of age. We analyzed data of a total of 12,324 participants (5,375 males and 6,949 females), after excluding 4,800 subjects with missing appendicular skeletal muscle mass (ASM) data and 605 who did not undergo blood testing.

Measurement of low muscle mass. ASM was measured by dual X-ray absorptiometry (DXA) (QDR 4500A; Hologic, Inc., Bedford, MA). Low muscle mass was defined using the criteria of the Foundation for the National Institutes of Health (FNIH) Sarcopenia Project (*22*). The FNIH Sarcopenia Project defined sarcopenia by assessing muscle function and muscle mass, and low muscle mass was defined as the ASM divided by body mass index (BMI) (ASM [kg]÷BMI [kg/m^2]) <0.789 in males and <0.512 in females.

Measurement of serum 25(OH)D concentration. Following an overnight fast, blood was collected using a sterilized disposable syringe and stored in a -75°C freezer until required. Serum 25(OH)D concentration was measured by radioimmunoassay (RIA) using a 25(OH)D 125I RIA Kit (Diasorin, Stillwater, MN) with a γ-counter (1470Wizard; PerkinElmer, Turku, Finland). The interassay coefficient of variation (CV) was 2.8–6.2% for the 2009 samples and 1.9–6.1% for the 2010 samples. The 25(OH)D concentration was classified as deficient at <10.0 ng/mL, insufficient at 10.0–19.9 ng/mL, sufficient at 20.0–29.9 ng/mL, and optimal at ≥ 30 ng/mL.

Covariates. Trained investigators interviewed the subjects individually using the questionnaire. Weight was measured to the nearest 0.1 kg while the subjects were dressed in light clothes, and height was measured to the nearest 0.1 cm in stocking feet. Waist circumfer-

Table 1. Baseline characteristics of subjects.

Variable	*N*	e% (SE) or Mean±SE
Number	12,324	
Low muscle mass	1,454	9.5 (0.5)
25(OH)D (ng/mL)		17.8±0.2
Sex		
Male	5,375	50.1 (0.5)
Female	6,949	49.9 (0.5)
Age (y)		
20–39	3,918	
40–64	5,829	
≧65	2,577	12.8 (0.5)
Height (cm)		164.0±0.1
Weight (kg)		63.9±0.1
Body mass index (kg/m^2)		23.7±0.0
Waist circumference (cm)		80.9±0.2
Survey years		
2009	6,766	51.9 (1.0)
2010	5,558	48.1 (1.0)
Season of blood collection		
Spring (Mar-May)	3,085	26.2 (2.6)
Summer (Jun–Aug)	3,209	25.9 (2.6)
Autumn (Sep–Nov)	2,934	21.8 (2.3)
Winter (Dec–Feb)	3,096	26.1 (2.6)
Monthly household income		
Lowest	2,423	16.4 (0.6)
Medium–lowest	2,956	24.8 (0.8)
Medium–highest	3,411	29.6 (0.8)
Highest	3,392	29.2 (0.9)
Education level		
≦Elementary school	3,178	19.2 (0.7)
Middle school	1,391	10.0 (0.3)
High school	4,169	38.9 (0.8)
≧College	3,510	31.9 (0.8)
Marital status		
Married	10,663	79.8 (0.7)
Unmarried	1,643	20.2 (0.7)
Residence		
Urban	9,362	79.9 (2.0)
Rural	2,962	20.1 (2.0)
Current smoking	2,679	27.0 (0.5)
Monthly drinking	6,608	59.8 (0.7)
Regular walking[1]	5,261	43.7 (0.6)
Strength training[2]	3,164	71.1 (0.6)
Use of dietary supplements	4,368	35.2 (0.6)
Number of comorbidities[3]		
0	7,041	63.7 (0.7)
1	3,077	22.8 (0.5)
2	1,502	9.7 (0.4)
≥3	652	3.9 (0.2)

e%, estimated percentage; SE, standard error.

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

[2] Strength training was indicated as 'yes' when the subject exercised strength training for more than 30 min at a time and more than one time per week.

[3] Comorbidities were included hypertension, diabetes, dyslipidemia, stroke, myocardial infarction, angina pectoris, arthritis, cancer, liver cirrhosis, and kidney failure.

Table 2. General characteristics of subjects according to the 25(OH)D levels.

Variable	25(OH)D level (ng/mL)				*p*-value
	Deficient <10.0	Insufficient 10.0–19.9	Sufficient 20.0–29.9	Optimal ≥30.0	
Low muscle mass	11.9 (1.5)	8.9 (0.5)	9.8 (0.7)	10.5 (1.8)	
Sex					<0.001
Male	30.8 (1.8)	47.2 (0.7)	60.2 (1.1)	63.9 (1.8)	
Female	69.2 (1.8)	52.8 (0.7)	39.8 (1.1)	36.1 (1.8)	
Age (y)					<0.001
20–39	51.7 (2.2)	45.1 (1.1)	31.1 (1.4)	20.7 (2.4)	
40–64	37.8 (1.8)	44.2 (0.9)	52.7 (1.2)	56.4 (2.4)	
≧65	10.4 (1.2)	10.8 (0.5)	16.2 (0.9)	22.8 (1.7)	
Height (cm)	161.8±0.4	164.1±0.2	164.4±0.2	163.9±0.4	<0.001
Weight (kg)	59.9±0.5	64.0±0.2	64.8±0.3	63.8±0.5	<0.001
Body mass index (kg/m^2)	22.8±0.2	23.7±0.1	23.9±0.1	23.7±0.1	<0.001
Waist circumference (cm)	77.4±0.5	80.7±0.2	82.2±0.2	82.8±0.5	<0.001
Survey years					0.820
2009	52.1 (3.1)	52.4 (1.3)	51.1 (2.0)	49.6 (4.2)	
2010	47.9 (3.1)	47.6 (1.3)	48.9 (2.0)	50.4 (4.2)	
Season of blood collection					<0.001
Spring (Mar-May)	36.9 (4.2)	30.3 (2.8)	17.0 (2.3)	8.7 (2.2)	
Summer (Jun–Aug)	14.9 (2.5)	21.3 (2.4)	37.1 (3.4)	42.1 (5.1)	
Autumn (Sep–Nov)	8.9 (1.6)	19.4 (2.3)	28.2 (3.0)	36.8 (5.0)	
Winter (Dec–Feb)	39.3 (4.3)	29 (2.8)	17.7 (2.4)	12.4 (2.9)	
Monthly household income					0.001
Lowest	17.8 (1.8)	15.1 (0.7)	18.0 (1.0)	21.6 (2.0)	
Medium-lowest	22.4 (1.9)	24.6 (0.9)	25.3 (1.2)	28.9 (2.0)	
Medium-highest	32.3 (2.2)	30.4 (0.9)	27.4 (1.1)	25.8 (2.0)	
Highest	27.5 (2.4)	29.9 (1.1)	29.3 (1.4)	23.7 (2.1)	
Education level					<0.001
≦Elementary school	15.2 (1.4)	16.4 (0.7)	24.4 (1.2)	31.4 (2.6)	
Middle school	7.8 (1.1)	9.2 (0.4)	11.4 (0.7)	16.1 (1.7)	
High school	42.4 (2.2)	40.1 (0.9)	36.5 (1.2)	30.3 (2.6)	
≧College	34.6 (2.2)	34.2 (1.0)	27.6 (1.2)	22.2 (2.7)	
Marital status					<0.001
Married	68.5 (2.3)	77.7 (0.9)	86.0 (1.0)	90.3 (1.6)	
Unmarried	31.5 (2.3)	22.3 (0.9)	14.0 (1.0)	9.7 (1.6)	
Residence					<0.001
Urban	88.5 (2.2)	83.2 (1.9)	72.7 (2.9)	63.0 (4.8)	
Rural	11.5 (2.2)	16.8 (1.9)	27.3 (2.9)	37.0 (4.8)	
Current smoking	24.9 (1.7)	26.4 (0.7)	28.5 (1.0)	30.3 (2.2)	0.089
Monthly drinking	51.4 (2.0)	59.3 (0.8)	62.9 (1.1)	62.3 (2.4)	<0.001
Regular walking[1]	38.5 (2.1)	43.4 (0.8)	45.3 (1.1)	47.1 (2.0)	0.010
Strength training[2]	25.8 (2.1)	27.7 (0.7)	32.5 (1.2)	30.2 (2.3)	0.001
Use of dietary supplements	29.0 (2.0)	34.8 (0.8)	37.4 (1.1)	37.5 (2.6)	0.003
Number of comorbidities[3]					<0.001
0	70.1 (1.9)	66.6 (0.8)	57.4 (1.1)	51.6 (2.3)	
1	18.4 (1.6)	21.4 (0.6)	26.0 (1.0)	29.3 (2.0)	
2	9.0 (1.1)	8.4 (0.4)	12.0 (0.7)	13.8 (1.5)	
≥3	2.5 (0.5)	3.6 (0.2)	4.6 (0.4)	5.3 (1.0)	

All values are presented as estimated percentage (standard error) or mean±standard error.

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

[2] Strength training was indicated as 'yes' when the subject exercised strength training for more than 30 min at a time and more than one time per week.

[3] Comorbidities were included hypertension, diabetes, dyslipidemia, stroke, myocardial infarction, angina pectoris, arthritis, cancer, liver cirrhosis, and kidney failure.

Table 3. The ORs for low muscle mass according to the level of 25(OH)D.

25(OH)D level (ng/mL)	Non-adjusted OR (95%CI)	Model 1[1] OR (95%CI)	Model 2[2] OR (95%CI)	Model 3[3] OR (95%CI)
<10.0	reference	reference	reference	reference
10.0–19.9	0.72 (0.55–0.95)	0.59 (0.44–0.80)	0.57 (0.43–0.77)	0.55 (0.40–0.75)
20.0–29.9	0.81 (0.59–1.11)	0.49 (0.34–0.70)	0.48 (0.34–0.69)	0.47 (0.33–0.68)
≥30.0	0.87 (0.53–1.41)	0.44 (0.26–0.74)	0.43 (0.25–0.75)	0.39 (0.24–0.64)

[1] Adjusted by sex, age, survey years and season of blood collection.
[2] Adjusted by Model 1 variables plus waist circumference, monthly household income, education level, marital status and residence.
[3] Adjusted by Model 2 variables plus current smoking, monthly drinking, regular walking, strength training, use of dietary supplements and number of comorbidities.

ence was measured to the nearest 0.1 cm at expiration in a horizontal plane around the abdomen midway between the lowest rib and the iliac crest. Monthly household income was divided into quartiles. Educational level was divided into <6, 7–9, 10–12, and ≥13 y. Marriage status was classified as unmarried or married, and area of residence was divided into urban or rural locations. Current smoking was defined as smoking frequently or occasionally, and monthly drinking was defined as one or more drinking experiences during the last month. Regular walking was indicated as 'yes' when the subject walked for more than 30 min at a time and more than five times per week. Strength training was indicated as 'yes' when the subject exercised strength training for more than 30 min at a time and more than one time per week. Use of dietary supplements was indicated as 'yes' when the subject took dietary supplements for >2 wk during the previous year. Participants who self-reported physician-diagnosed hypertension, diabetes, dyslipidemia, stroke, myocardial infarction, angina pectoris, arthritis, cancer, liver cirrhosis, and kidney failure were considered to have a comorbid condition and were classified into four groups according to the number of comorbidities (0, 1, 2, or ≥3).

Statistical analysis. Data were analyzed using SPSS ver. 23.0. As the KNHANES data are generated from a complex sampling survey design, all analyses were conducted using survey weighting. The survey responses were weighted based on a multilevel, multiple probability sampling design. Data are expressed as estimated percentage (standard error [SE]) or as mean±SE. The relationship of each dependent variable with the 25(OH)D level was analyzed by χ^2 test or analysis of variance. A multivariate logistic regression analysis was performed to investigate the association of low muscle mass with the 25(OH)D level. Model 1 was adjusted for sex, age, survey year, and season of blood collection. Model 2 was adjusted for the Model 1 variables plus waist circumference, monthly household income, educational level, marital status, and area of residence. Model 3 was adjusted for the Model 2 variables plus current smoking, monthly drinking, regular walking, strength training, use of dietary supplements, and number of comorbidities. A value of $p<0.05$ was considered indicative of statistical significance.

RESULTS

Baseline characteristics

The baseline characteristics of the 12,324 subjects (5,375 males and 6,949 females) are shown in Table 1. The prevalence of low muscle mass was 9.5% and the mean 25(OH)D level was 17.8±0.2 ng/mL. The mean age of the subjects was 44.9±0.3 y and their mean waist circumference was 80.9±0.2 cm. Among the subjects, 27.0% currently smoked, 59.8% had consumed alcohol in the past month, 43.7% were regularly walked, and 35.2% used dietary supplements.

Characteristics of subjects according to 25(OH)D levels

The characteristics of the subjects according to 25(OH)D level are shown in Table 2. A higher 25(OH)D level was associated with male sex, older age, larger waist circumference, blood collection in summer, higher monthly household income, higher educational level, being married, residence in a rural area, more frequent walking, more frequent use of dietary supplements, and larger number of comorbidities.

Odds ratios (ORs) for low muscle mass according to 25(OH)D level

The odds ratios (ORs) for low muscle mass according to 25(OH)D level are shown in Table 3. When adjusted for sex, age, survey year, and season of blood collection (Model 1), low muscle mass was significantly associated with a low 25(OH)D level (for 10.0–19.9 vs. <10.0 ng/mL: OR=0.59, 95% confidence interval [CI] 0.44–0.80; for 20.0–29.9 vs. <10.0 ng/mL: OR=0.49, 95% CI 0.34–0.70; and for ≥30.0 vs. <10.0 ng/mL: OR=0.44, 95% CI 0.26–0.74). When additionally adjusted for waist circumference, monthly household income, educational level, marital status, area of residence, current smoking, monthly drinking, regular walking, strength training, use of dietary supplements, and number of comorbidities (Model 3), low muscle mass was significantly associated with a low 25(OH)D level (for 10.0–19.9 vs. <10.0 ng/mL: OR=0.55, 95% CI 0.40–0.75; for 20.0–29.9 vs. <10.0 ng/mL: OR=0.47, 95% CI 0.33–0.68; and for ≥30.0 vs. <10.0 ng/mL: OR=0.39, 95% CI 0.24–0.64).

Table 4. The ORs for low muscle mass stratified by age group according to the level of 25(OH)D.

Age (y)	25(OH)D level (ng/mL)	Non-adjusted OR (95%CI)	Model 1[1] OR (95%CI)	Model 2[2] OR (95%CI)	Model 3[3] OR (95%CI)
20–39	<10.0	reference	reference	reference	reference
	10.0–19.9	0.74 (0.42–1.30)	0.64 (0.35–1.16)	0.58 (0.32–1.05)	0.53 (0.29–0.97)
	20.0–29.9	0.68 (0.33–1.40)	0.59 (0.27–1.28)	0.55 (0.26–1.17)	0.55 (0.25–1.17)
	≥30.0	0.09 (0.01–0.69)	0.09 (0.01–0.67)	0.08 (0.01–0.65)	0.08 (0.01–0.68)
40–64	<10.0	reference	reference	reference	reference
	10.0–19.9	0.60 (0.40–0.90)	0.56 (0.36–0.87)	0.55 (0.35–0.85)	0.53 (0.34–0.84)
	20.0–29.9	0.56 (0.34–0.91)	0.52 (0.32–0.87)	0.48 (0.29–0.80)	0.44 (0.26–0.74)
	≥30.0	0.61 (0.32–1.18)	0.56 (0.29–1.11)	0.46 (0.23–0.95)	0.43 (0.22–0.86)
≥65	<10.0	reference	reference	reference	reference
	10.0–19.9	0.67 (0.43–1.03)	0.68 (0.43–1.08)	0.63 (0.39–1.01)	0.59 (0.36–0.96)
	20.0–29.9	0.53 (0.32–0.85)	0.56 (0.33–0.94)	0.51 (0.30–0.86)	0.48 (0.27–0.84)
	≥30.0	0.40 (0.21–0.74)	0.46 (0.23–0.89)	0.43 (0.22–0.85)	0.37 (0.19–0.73)

[1] Adjusted by sex, survey years and season of blood collection.
[2] Adjusted by Model 1 variables plus waist circumference, monthly household income, education level, marital status and residence.
[3] Adjusted by Model 2 variables plus current smoking, monthly drinking, regular walking, strength training, use of dietary supplements and number of comorbidities.

ORs for low muscle mass stratified by age group according to 25(OH)D level

The ORs for low muscle mass stratified by age group according to 25(OH)D level are shown in Table 4. After adjusting for covariates (Model 3), in the 20–39-y age group, low muscle mass was significantly associated with a low 25(OH)D level (for 10.0–19.9 vs. <10.0 ng/mL: OR=0.53, 95% CI 0.29–0.97; for ≥30.0 vs. <10.0 ng/mL: OR=0.08, 95% CI 0.01–0.68). In the 40–64-y age group, low muscle mass was significantly associated with a low 25(OH)D level (for 10.0–19.9 vs. <10.0 ng/mL: OR=0.53, 95% CI 0.34–0.84; for 20.0–29.9 vs. <10.0 ng/mL: OR=0.44, 95% CI 0.26–0.74; for ≥30.0 vs. <10.0 ng/mL: OR=0.43, 95% CI 0.22–0.86). Finally, low muscle mass was also significantly associated with a low 25(OH)D level in subjects aged ≥65 y (for 10.0–19.9 vs. <10.0 ng/mL: OR=0.59, 95% CI 0.36–0.96; for 20.0–29.9 vs. <10.0 ng/mL: OR=0.48, 95% CI 0.27–0.84; and for ≥30.0 vs. <10.0 ng/mL: OR=0.37, 95% CI 0.19–0.73).

DISCUSSION

We investigated the relationship between muscle mass and the 25(OH)D level using data from the 2009–2010 KNHANES. After adjustment for covariates, low muscle mass was significantly associated with low 25(OH)D levels in all age groups.

Muscle mass can be measured by various methods, for example, measurement of ASM by DXA corrected for the square of the height (ASM÷height^2) (*3*) or by weight (ASM÷weight) (*7*). Low muscle mass was defined as a value less than −2 standard deviations (SDs) or −1 SD of the mean of the younger reference population. The use of these definitions is hampered by the need for younger reference groups, which differ among studies, and this hampers comparative analyses. To clarify the definition and diagnostic criteria, the FNIH Sarcopenia Project used data from nine cohorts and defined low muscle mass as a value of ASM÷BMI <0.789 for males and <0.512 for females (*22*). In a previous study using data from the 2008–2009 KNHANES, the prevalence of low muscle mass in the South Korean population aged 20 y or older was 9.7% for males and 11.8% for females by the ASM÷weight definition and 12.4% for males and 0.1% for females by the ASM÷height^2 definition (*23*). Using the definition of the FNIH Sarcopenia Project, we found that the prevalence of low muscle mass in the South Korean population aged 20 y or older was 9.5% (8.3% for males and 10.6% for females).

In this study, after adjusting for covariates, as the level of 25(OH)D increased, the ORs for low muscle mass significantly decreased. In the Ansan Geriatric study involving 484 elderly South Korean adults, a lower 25(OH)D level was associated with low muscle mass in males but not in females (*18*). In the Tasmanian Older Adult Cohort Study involving 686 Australian adults aged 50 y or older, the 25(OH)D level was significantly associated with the appendicular lean mass percentage (*16*). In a study involving 667 US subjects aged 20 y or older, there was no consistent association between the 25(OH)D level and muscle mass in males or females (*19*). This may be because subjects' ethnicities and ages differed, as did the methods used to diagnose low muscle mass.

Several mechanisms could underlie the link between vitamin D deficiency and muscle mass. First, the vitamin D–parathyroid hormone pathway is associated with low muscle mass. Parathyroid hormone increases the serum calcium level. A lack of vitamin D increases

the secretion of parathyroid hormone, which increases the calcium concentration in myocytes, promoting the synthesis of cytokines and deteriorating the structure and function of muscle (*24*, *25*). Also, vitamin D binds to receptors in muscle cells, promoting muscle growth and protein synthesis (*14*). Therefore, vitamin D deficiency leads to proximal muscle weakness and atrophy of type II muscle fibers (*26*). In addition, inflammation is a risk factor for a decrease in muscle mass (*27*), whereas vitamin D ameliorates inflammation and prevents muscle weakening (*28*).

Previous studies have evaluated the relationship between vitamin D and low muscle mass in elderly people, a group in whom the incidence of low muscle mass is high and is associated with decreased mobility, an increased risk of falls and fractures (*29*), decreased daily functioning and independent living, and an increased risk of death (*30*). However, because younger people in South Korea have a low level of vitamin D (*31*), an understanding of the relationship between vitamin D and low muscle mass at all ages is needed. We found that the prevalence of low muscle mass decreased significantly with increasing 25(OH)D level in all age groups after adjusting for confounding variables.

The present study has several strengths. We used data representative of the entire South Korean population. Furthermore, whereas previous studies focused on the elderly population, we examined both the older and the general adult population. However, this study has several limitations. First, its cross-sectional design prevented the identification of cause-and-effect relationships. Second, the definition of low muscle mass was based on the criteria of the Sarcopenia Project, which were developed using the US population; this may have resulted in overestimation of the prevalence of low muscle mass among South Koreans. However, compared with the previous study that used data from the 2008–2009 KNHANES and defined low muscle mass based on ASM÷weight, there was no significant difference in the prevalence of low muscle mass (9.7% for males and 11.8% for females vs. 8.3% for males and 10.6% for females in this study).

In conclusion, after adjustment for covariates, a lower 25(OH)D level was associated with low muscle mass in South Korean adults. Moreover, when stratified according to age group, the association between the 25(OH)D level and low muscle mass was significant in all age groups.

Authorship

Research conception and design: SWC and DGJ; statistical analysis of the data: SWC and SYR; interpretation of the data: JP and DGJ; writing of the manuscript: DGJ.

Disclosure of state of COI

No conflicts of interest to be declared.

REFERENCES

1) Scott D, Hayes A, Sanders KM, Aitken D, Ebeling PR, Jones G. 2014. Operational definitions of sarcopenia and their associations with 5-year changes in falls risk in community-dwelling middle-aged and older adults. *Osteoporos Int* **25**: 187–193.

2) Tanimoto Y, Watanabe M, Sun W, Sugiura Y, Tsuda Y, Kimura M, Hayashida I, Kusabiraki T, Kono K. 2012. Association between sarcopenia and higher-level functional capacity in daily living in community-dwelling elderly subjects in Japan. *Arch Gerontol Geriatr* **55**: e9–13.

3) Baumgartner RN, Koehler KM, Gallagher D, Romero L, Heymsfield SB, Ross RR, Garry PJ, Lindeman RD. 1998. Epidemiology of sarcopenia among the elderly in New Mexico. *Am J Epidemiol* **147**: 755–763.

4) Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, Martin FC, Michel JP, Rolland Y, Schneider SM, Topinková E, Vandewoude M, Zamboni M; European Working Group on Sarcopenia in Older People. 2010. Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on Sarcopenia in Older People. *Age Ageing* **39**: 412–423.

5) Chen LK, Liu LK, Woo J, Assantachai P, Auyeung TW, Bahyah KS, Chou MY, Chen LY, Hsu PS, Krairit O, Lee JSW, Lee WJ, Lee Y, Liang CK, Limpawattana P, Lin CS, Peng LN, Satake S, Suzuki T, Won CW, Wu CH, Wu SN, Zhang T, Zeng P, Akishita M, Arai H. 2014. Sarcopenia in Asia: Consensus report of the Asian Working Group for Sarcopenia. *J Am Med Dir Assoc* **15**: 95–101.

6) Kim TN, Yang SJ, Yoo HJ, Lim KI, Kang HJ, Song W, Seo JA, Kim SG, Kim NH, Baik SH, Choi DS, Choi KM. 2009. Prevalence of sarcopenia and sarcopenic obesity in Korean adults: the Korean sarcopenic obesity study. *Int J Obes* **33**: 885–892.

7) Janssen I, Heymsfield SB, Ross R. 2002. Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. *J Am Geriatr Soc* **50**: 889–896.

8) Zhang R, Naughton DP. 2010. Vitamin D in health and disease: Current perspectives. *Nutr J* **9**: 65.

9) Prentice A, Goldberg GR, Schoenmakers I. 2008. Vitamin D across the lifecycle: physiology and biomarkers. *Am J Clin Nutr* **88**: 500S–506S.

10) Gandini S, Boniol M, Haukka J, Byrnes G, Cox B, Sneyd MJ, Mullie P, Autier P. 2011. Meta-analysis of observational studies of serum 25-hydroxyvitamin D levels and colorectal, breast and prostate cancer and colorectal adenoma. *Int J Cancer* **128**: 1414–1424.

11) Leu Agelii M, Lehtinen-Jacks S, Zetterberg H, Sundh V, Björkelund C, Lissner L. 2017. Low vitamin D status in relation to cardiovascular disease and mortality in Swedish women—Effect of extended follow-up. *Nutr Metab Cardiovasc Dis* **27**: 1143–1151.

12) Lips P, Eekhoff M, van Schoor N, Oosterwerff M, de Jongh R, Krul-Poel Y, Simsek S. 2017. Vitamin D and type 2 diabetes. *J Steroid Biochem Mol Biol* **173**: 280–285.

13) Holick MF. 2002. Vitamin D: the underappreciated D-lightful hormone that is important for skeletal and cellular health. *Curr Opin Endocrinol Diabetes* **9**: 87–98.

14) Boland R. 1986. Role of vitamin D in skeletal muscle function. *Endocr Rev* **7**: 434–448.

15) Kim MK, Baek KH, Song KH, Il Kang M, Park CY, Lee WY, Oh KW. 2011. Vitamin D deficiency is associated with sarcopenia in older Koreans, regardless of obesity: the Fourth Korea National Health and Nutrition Examination Surveys (KNHANES IV) 2009. *J Clin Endocrinol Metab* **96**: 3250–3256.

16) Scott D, Blizzard L, Fell J, Ding C, Winzenberg T, Jones G. 2010. A prospective study of the associations between 25-hydroxy-vitamin D, sarcopenia progression and physical activity in older adults. *Clin Endocrinol (Oxf)* **73**: 581–587.

17) Park S, Ham JO, Lee BK. 2014. A positive association of vitamin D deficiency and sarcopenia in 50 year old women, but not men. *Clin Nutr* **33**: 900–905.

18) Seo JA, Cho H, Eun CR, Yoo HJ, Kim SG, Choi KM, Baik SH, Choi DS, Park MH, Han C, Kim NH. 2012. Association between visceral obesity and sarcopenia and vitamin D deficiency in older Koreans: the Ansan Geriatric Study. *J Am Geriatr Soc* **60**: 700–706.

19) Marantes I, Achenbach SJ, Atkinson EJ, Khosla S, Melton LJ, Amin S. 2011. Is vitamin D a determinant of muscle mass and strength? *J Bone Miner Res* **26**: 2860–2871.

20) 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.

21) Kweon S, Kim Y, Jang MJ, Kim Y, Kim K, Choi S, Chun C, Khang YH, Oh K. 2014. Data resource profile: the Korea National Health and Nutrition Examination Survey (KNHANES). *Int J Epidemiol* **43**: 69–77.

22) Studenski SA, Peters KW, Alley DE, Cawthon PM, McLean RR, Harris TB, Ferrucci L, Guralnik JM, Fragala MS, Kenny AM, Kiel DP, Kritchevsky SB, Shardell MD, Dam TTL, Vassileva MT. 2014. The FNIH sarcopenia project: rationale, study description, conference recommendations, and final estimates. *J Gerontol A Biol Sci Med Sci* **69**: 547–558.

23) Kim YS, Lee Y, Chung YS, Lee DJ, Joo NS, Hong D, Song Ge, Kim HJ, Choi YJ, Kim KM. 2012. Prevalence of sarcopenia and sarcopenic obesity in the Korean population based on the Fourth Korean National Health and Nutritional Examination Surveys. *J Gerontol A Biol Sci Med Sci* **67**: 1107–1113.

24) Baczynski R, Massry SG, Magott M, el-Belbessi S, Kohan R, Brautbar N. 1985. Effect of parathyroid hormone on energy metabolism of skeletal muscle. *Kidney Int* **28**: 722–727.

25) Visser M, Pahor M, Taaffe DR, Goodpaster BH, Simonsick EM, Newman AB, Nevitt M, Harris TB. 2002. Relationship of interleukin-6 and tumor necrosis factor-alpha with muscle mass and muscle strength in elderly men and women: the Health ABC Study. *J Gerontol A Biol Sci Med Sci* **57**: M326–332.

26) Visser M, Deeg DJH, Lips P, Longitudinal Aging Study Amsterdam. 2003. Low vitamin D and high parathyroid hormone levels as determinants of loss of muscle strength and muscle mass (sarcopenia): the Longitudinal Aging Study Amsterdam. *J Clin Endocrinol Metab* **88**: 5766–5772.

27) Roth SM, Metter EJ, Ling S, Ferrucci L. 2006. Inflammatory factors in age-related muscle wasting. *Curr Opin Rheumatol* **18**: 625–630.

28) Schleithoff SS, Zittermann A, Tenderich G, Berthold HK, Stehle P, Koerfer R. 2006. Vitamin D supplementation improves cytokine profiles in patients with congestive heart failure: a double-blind, randomized, placebo-controlled trial. *Am J Clin Nutr* **83**: 754–759.

29) Remelli F, Vitali A, Zurlo A, Volpato S. 2019. Vitamin D deficiency and sarcopenia in older persons. *Nutrients* **11**: 2861.

30) Lauretani F, Russo CR, Bandinelli S, Bartali B, Cavazzini C, Di Iorio A, Corsi AM, Rantanen T, Guralnik JM, Ferrucci L. 2003. Age-associated changes in skeletal muscles and their effect on mobility: an operational diagnosis of sarcopenia. *J Appl Physiol* **95**: 1851–1860.

31) Choi HS, Oh HJ, Choi H, Choi WH, Kim JG, Kim KM, Kim KJ, Rhee Y, Lim SK. 2011. Vitamin D insufficiency in Korea—a greater threat to younger generation: the Korea National Health and Nutrition Examination Survey (KNHANES) 2008. *J Clin Endocrinol Metab* **96**: 643–651.