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Original Article

Effects of Vitamin D on Depression, Cognitive Function, and Physical Function in Elderly Individuals Living Alone

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SUMMARY

Background: We examined the effects of vitamin D on depression, cognitive function, and physical function in elderly, community-dwelling individuals living alone.
Methods: In this non-equivalent, control-group experimental study, participants with serum vitamin D levels < 20 ng/mL and who lived alone were enrolled from eight senior centers in S city, Gyeonggi-do. Forty-six individuals were assigned to the experimental group and forty-eight to the control group. Vitamin D supplements and exercise programs were prescribed to the experimental group; the control group was prescribed only exercise programs. Treatment duration was 12 weeks. Depression, cognitive function, physical function (muscle mass, grip strength, static balance, time to walk a standard course, and arm flexibility), vitamin D and calcium levels were measured before and after treatment. Collected data were analyzed using chi-squared test, Fisher's exact test, *t*-test and multivariate logistic regression analysis.
Results: Depression levels and cognitive function improved in both groups, the difference was not significant. Vitamin D levels ($p < 0.001$), muscle mass ($p = 0.014$), and time to walk a standard course ($p = 0.012$) improved in the experimental group.
Conclusion: Vitamin D supplementation for 12 weeks in vitamin-D deficient elderly individuals living alone was associated with improved vitamin D levels, muscle mass, and time to walk a standard course.

1. Introduction

The increasing proportion of elderly individuals in Korea, particularly those living alone, poses serious socioeconomic challenges. In Korea, 13.6% of elderly individuals lived alone in 1994; this number increased to 23.0% in 2014.[1]

Since elderly individuals living alone do not have caregivers or people to communicate with, they have higher depression levels[2] and lower levels of mental health, including cognitive function, compared to those living with family members.[3] Additionally, 96% of elderly individuals living alone have chronic diseases and are at a higher risk of not receiving emergency help, owing to economic hardships and social isolation.[4]

Recent studies report an association between vitamin D and depression or cognitive function, owing to the specific function of vitamin D in the brain; however, results are inconsistent.[5–9] Some studies outside Korea demonstrated that low vitamin D levels are associated with high depression levels[5,6] and low degrees of cognitive function;[7] however, other studies did not uncover any significant relationship[8,9] or effect of vitamin D supplementation on depression.[10] It has also been shown that vitamin D supplementation improves walking ability, speed,[11] lower limb muscle strength, and mobility in the elderly,[12] and those with high vitamin D levels have better muscle strength and mobility.[13]

Studies on vitamin D and cognitive function in Korea have also been inconsistent. One study reported no association between vitamin D and depression or depressive symptoms.[14] Alternatively, vitamin D deficiency was shown to highly correlate with the occurrence of dementia and Alzheimer's disease.[15] Further, a study reported that vitamin D intake enhanced muscle mass and physical function in elderly individuals,[16] outlining the effects of vitamin D supplementation on physical function in elderly women.[16] Other studies have examined the effects of vitamin D supplementation in vitamin D-deficient elderly individuals.[16] To reach a consensus, we investigated the effects of vitamin D supplementation on depression, cognitive function, and physical function, in vitamin D-deficient elderly individuals living alone.

2. Patients and methods

2.1. Study design

Data from the pre- to post-intervention period were collected between November 28, 2014, and March 7, 2015 (Fig. 1). This investigation had a nonequivalent control group and pre-test–post-test design (Fig. 2). With reference to a previous study,[17] a required

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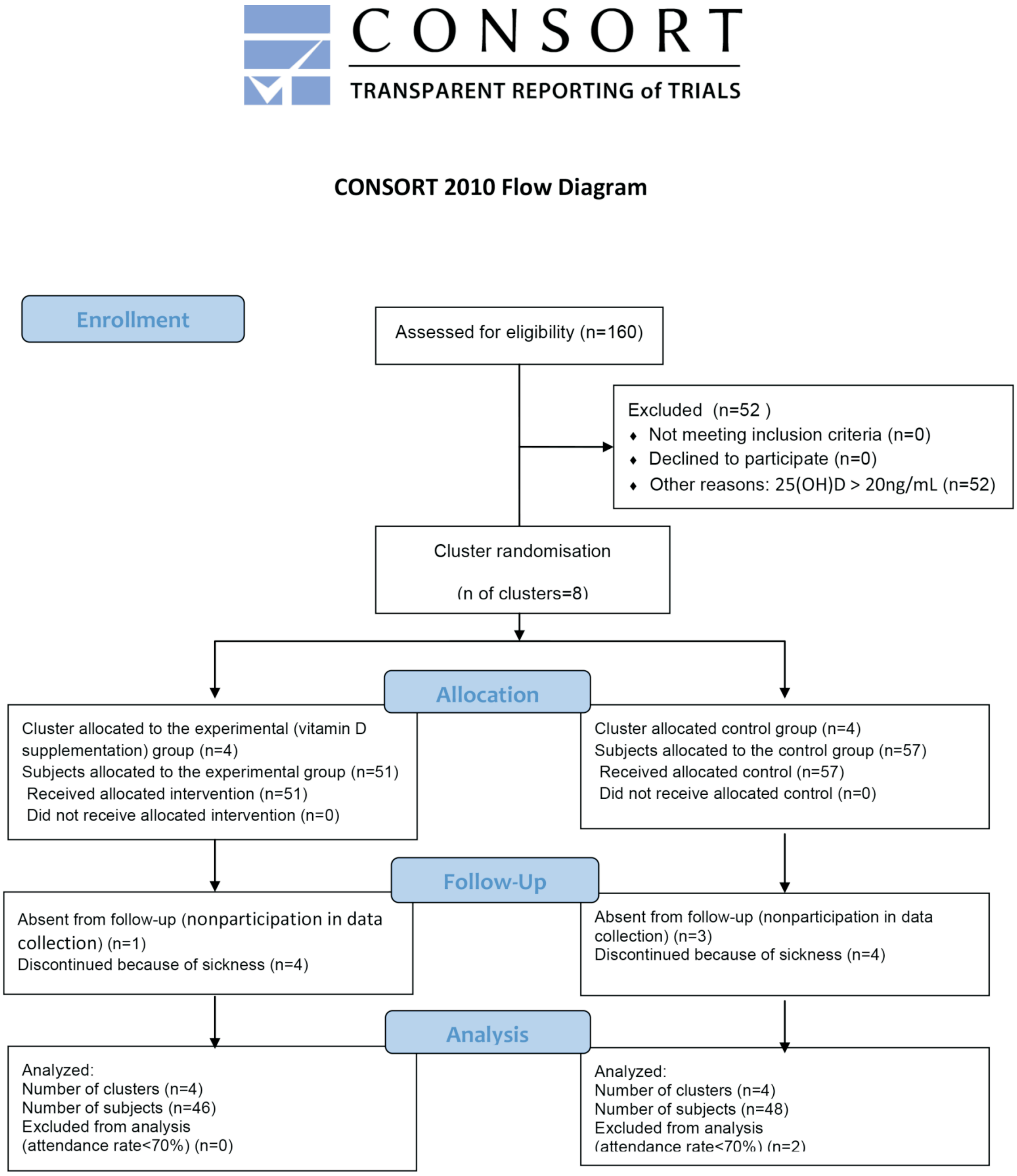

Fig. 1. CONSORT flow chart. 25(OH)D: serum 25-hydroxyvitamin D.

sample size of 45 individuals per group was computed with the assumptions of effect size, 0.6; significance level, 0.05; and power, 0.80 using unpaired t-test (G* Power 3.1.7 software; Heinrich-Heine-University Dusseldorf, Dusseldorf, Germany). Assuming an attrition rate of 20.0%,[18] we recruited 54 individuals per group (108 total). As 70% of elderly individuals in Korea are vitamin D-deficient, 160 eligible participants were recruited in the first stage.[19]

2.2. Setting and sample

Participants were aged > 65 years, lived alone, had serum 25-hydroxyvitamin D level < 20 ng/mL, and were members of senior centers in S city, Gyeonggi Province. Of 220 senior centers in S city, eight, to which > 15 elderly individuals living alone were registered and which had space for the study's exercise program, were selected. Based on a coin toss, four centers were assigned to the experimental vitamin D supplementation group (VDG) and the remaining to the control group (CG). Exclusion criteria were serum vitamin D level > 20 ng/mL, history of parathyroid disease or kidney disease, taking vitamin D or calcium supplements, receiving hormone therapy, or history of cardiac disease or cerebrovascular disease.

After serum vitamin D levels were measured, 51 participants were assigned to VDG and 57 to CG.

During the study period, five participants in VDG (illness, four; nonparticipation in data collection, one) and nine in CG (illness, four; nonparticipation in data collection, three; < 70% attendance during the exercise program, two) were dropped; the final sample size was 94 participants: 46 in VDG and 48 in CG (participation rate, 87.0%; Fig. 1).

2.3. Ethical considerations

Study objectives and methodology were approved by the In-

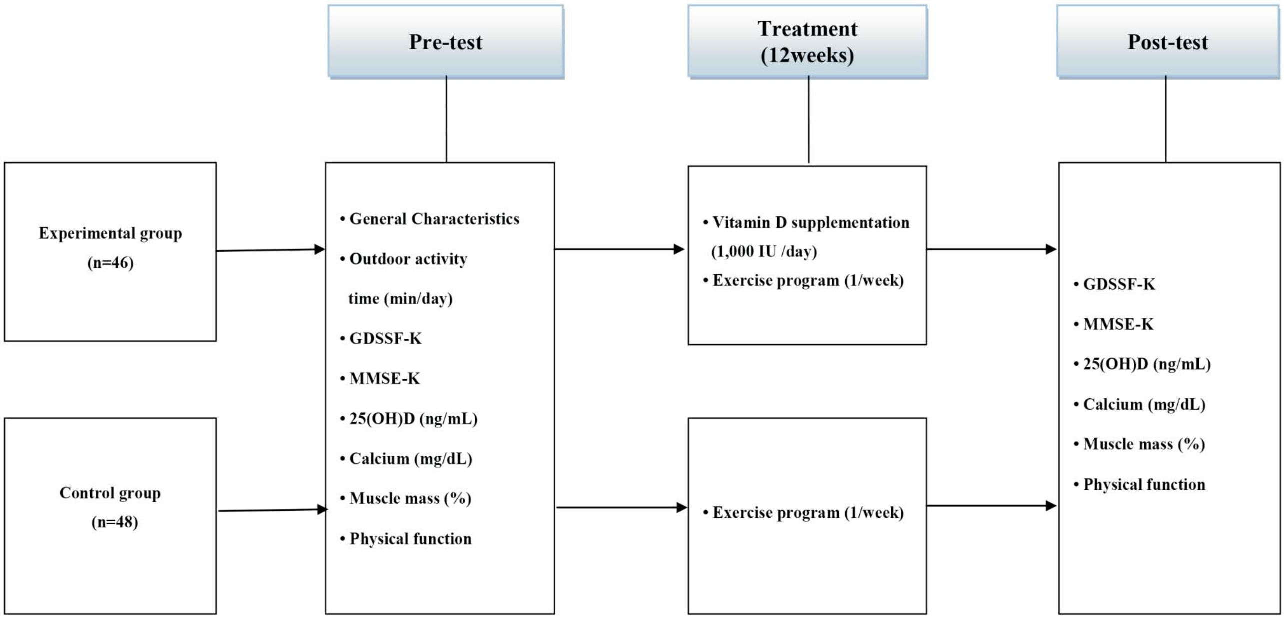

Fig. 2. Research design. GDSSF-K: geriatric depression scale short form-Korean version; MMSE-K: mini-mental state examination-Korean version; 25(OH)D: serum 25-hydroxyvitamin D. Physical parameters: grip strength (left, right; kg), static balance (sec), time to walk a standard course (sec), arm flexibility.

stitutional Review Board (IRB) of a university in Korea (IRB approval number: MC14OISE0101). Elderly individuals at senior centers were provided detailed explanations of study objectives and data-collection processes. Those who volunteered to be participated provided informed consent. The authors confirm that all ongoing and related trials for this intervention are registered (Registry name: CRIS, Registry number: KCT0002490, URL: https://cris.nih.go.kr/cris/index.jsp).

2.4. Intervention

2.4.1. Exercise program

Both groups underwent a 12-week exercise program that comprised 40-minute sessions, once weekly, including warm-ups, main, and closing exercises. The program instructor was provided details about the study beforehand (Table 1). At the beginning of each session, the instructor checked the physical condition of the participants and immediately had them stop if they felt pain in the joints or did not feel well; any health issues arising after the program were also evaluated.

2.4.2. Vitamin D supplementation

In addition to the exercise program, those in VDG took 1,000 IU vitamin D daily for 12 weeks — the minimum period taken for vitamin D supplementation to improve muscle strength without side effects.[16,20] Every week, a research assistant supplied individually packaged vitamin D tablets for that week; compliance was checked during the weekly exercise program as well as over phone, once weekly. Prior to commencement, participants were instructed to take one tablet per day.

2.5. Instruments

To ensure accuracy and consistency, a research assistant was instructed on the measurement techniques and other details before administering the tests.

2.5.1. Depression

To measure degree of depression, we used the Geriatric Depression Scale Short Form — Korean Version (GDSSF-K).[21] Permission to use GDSSF-K was obtained from the developer. GDSSF-K comprises 15 items, with scores ranging from 0–15; scores > 5 indicate depression and higher scores indicate depression of a higher severity. Cronbach's α was 0.86, indicating good reliability.

2.5.2. Cognitive function

The Mini-Mental State Examination — Korean version (MMSE-K) was used to assess cognitive function, which was revised and standardized for use among illiterate elderly individuals in Korea, based on the Mini-Mental State Examination.[22,23] Scores range from 0–30,

Table 1
Components of an exercise program.

Components	Number of motions	Contents	Duration (min)
Warm-up	9	Deep breathing and stretching	6
Main exercise	28	Range of motion (ROM) -Neck, shoulder, joint ROM Muscle strength, endurance -Hand grip, wrist press, knee-up holding, quadriceps setting exercise Weight-bearing exercise -Brisk walking Balance and cooperation	30
Closing exercise	4	Deep breathing and stretching	4

ROM: range of motion.

with higher scores indicating higher cognitive function. A score of < 23 indicates suspicions of dementia, while score of < 19 indicates dementia. Cronbach's α was 0.81, indicating good reliability.

2.5.3. Physical function

Muscle mass was measured using Biospace InBody U20 (Biospace, Seoul, Korea), which is based on direct segmental multi-frequency bioelectrical impedance analysis.

Grip strength was measured using TANITA NO-6103 (Tanita, Tokyo, Japan). Measurements were taken with the participant holding the machine's handle, in a standing position, feet comfortably apart, and arms naturally lowered. Grip strength was measured twice for both hand, with the average value was recorded.[24]

Static balance was measured with the participant standing on the dominant foot with eyes open and hands placed on the waist. Time taken for the participant to put the other foot down was measured in seconds and the average was recorded after two trials.[25]

Time to walk a standard course was measured as time taken to walk 4 m. Participants were asked to walk naturally, with normal step length, and the average was recorded after two trials.[16]

Arm flexibility was measured as distance between the middle fingers, as the participant maximally lowered the right arm from a raised position, while simultaneously maximally raising the left arm from the waist toward the shoulder. The average of two trials was recorded.[25]

2.5.4. Vitamin D and calcium levels

To measure serum vitamin D and calcium levels, blood (3 mL for vitamin D; 5 mL for calcium) was drawn from the brachial vein, stored in a refrigerator, and promptly sent for analysis using radio-immunoassay for vitamin D and colorimetric assay for calcium. Overnight fasting blood samples were collected at senior centers on specific days for serum vitamin D and serum calcium measurements.

2.6. Data collection

Data were collected between November 28, 2014, and March 7, 2015. In total, 160 elderly individuals provided written consent, and those with serum vitamin D levels < 20 ng/mL were selected ($n = 108$).

Depression level, cognitive function, physical function (muscle mass, grip strength, static balance, time to walk a standard course, and flexibility), vitamin D level, and calcium level were measured before and after the treatment.

2.7. Data analysis

Data were analyzed using SAS for Windows (Version 9.3; SAS Institute Inc., USA). General characteristics of the groups are reported using descriptive statistics. Data on homogeneity of the general characteristics, time spent on outdoor activities, use of sunscreen, and vitamin D intake were analyzed using a chi-squared test, Fisher's exact test, or *t*-test. A *t*-test was used for homogeneity testing on depression, cognitive function, physical function, vitamin D level, and calcium level. Within-group differences between the pre- and post-treatment periods were evaluated using a paired *t*-test, and between-group differences were evaluated using a multivariate logistic regression analysis. *P*-values were two-sided, and $p < 0.05$ was considered to be statistically significant.

3. Results

There were no differences in the general characteristics or baseline variables between the groups (Table 2).

Depression score decreased in VDG ($p = 0.007$); no such difference was noted in CG ($p = 0.852$) (Table 3). But between-group differences in the pre- and post-treatment changes were not significant ($p = 0.169$) (Table 4).

Cognitive function score increased in VDG from 22.9 before treatment to 24.1 after treatment ($p = 0.004$), while that of CG increased from 23.8 to 24.6 ($p = 0.019$) (Table 3). Thus, between-group difference in pre- and post-treatment change was not significant ($p = 0.114$) (Table 4).

Serum vitamin D level in VDG increased ($p < 0.001$), and there was no significant difference in CG ($p = 0.218$) (Table 3). Between-group difference in pre- and post-treatment change was significant ($p < 0.001$) (Table 4).

Change in the muscle mass before and after treatment was not significant in VDG and significantly decreased in CG (Table 3). Therefore, between-group difference was significant ($p = 0.014$) (Table 4).

Change in the time to walk a standard course before and after treatment was positive in VDG and negative in CG (Table 3). Thus, between-group difference was significant ($p = 0.012$) (Table 4).

4. Discussion

It is essential to focus on the health status of elderly individuals living alone, and formulate relevant health management policies.

Table 2
General patient characteristics and baseline variables.

Characteristics	VDG (n = 46)	CG (n = 48)	t or χ^2	p
	Mean ± SD or n (%)			
Age (years)	77.8 ± 6.0	76.9 ± 6.5	0.72	0.474
Sex			0.13	0.718
Male	10 (21.74)	9 (18.75)		
Female	36 (78.26)	39 (81.25)		
Education			3.71	0.157
Illiteracy	20 (43.48)	18 (37.50)		
Elementary school	20 (43.48)	16 (33.33)		
≥ Middle school	6 (13.04)	14 (29.17)		
Alcohol use			1.25	0.265
Yes	12 (26.09)	8 (16.67)		
No	34 (73.91)	40 (83.33)		
Smoking[a]				1
Yes	3 (6.52)	3 (6.25)		
No	43 (93.48)	45 (93.75)		
Perceived health			2.67	0.264
Healthy	6 (13.04)	4 (8.33)		
Moderate	12 (26.09)	20 (41.67)		
Not healthy	28 (60.87)	24 (50.00)		
Sunscreen agents use			1.12	0.289
Yes	18 (39.13)	24 (50.00)		
No	28 (60.87)	24 (50.00)		
Outdoor activity time (min/day)	82.5 ± 68.7	63.1 ± 64.3	1.39	0.167
GDSSF-K	5.8 ± 4.0	5.2 ± 4.1	0.76	0.450
MMSE-K	22.9 ± 3.8	23.8 ± 3.6	- 1.18	0.241
25(OH)D (ng/mL)	14.0 ± 3.6	13.3 ± 3.0	1.13	0.262
Calcium (mg/dL)	9.2 ± 0.4	9.3 ± 0.4	- 1.71	0.090
Muscle mass (%)	34.2 ± 5.7	35.9 ± 4.8	- 1.65	0.102
GS (Lt) (kg)	17.6 ± 6.8	17.8 ± 5.3	- 0.17	0.867
GS (Rt) (kg)	17.4 ± 6.7	18.5 ± 4.6	- 0.95	0.345
SB (sec)	7.3 ± 9.2	11.2 ± 16.5	- 1.36	0.177
TW (sec)	6.8 ± 10.3	5.6 ± 2.9	0.32	0.749
AF (Lt) (cm)	26.8 ± 15.7	25.6 ± 13.4	0.37	0.714
AF (Rt) (cm)	25.2 ± 15.3	24.2 ± 13.2	0.32	0.751

[a] Fisher's exact test.
25(OH)D: serum 25-hydroxyvitamin D; AF: arm flexibility; CG: control group; GDSSF-K: geriatric depression scale short form—Korean version; GS: grip strength; Lt: left; MMSE-K: mini-mental state examination—Korean version; Rt: right; SB: static balance; SD: standard deviation; TW: time to walk a standard course (4 m); VDG: vitamin D supplementation group.

Table 3
Results of the pre and post intervention in the case-control groups.

Variables		Pre-test	Post-test	t^w	p
		Mean ± SD			
GDSSF-K	VDG	5.8 ± 4.0	4.8 ± 3.1	- 2.86	0.007
	CG	5.2 ± 4.1	5.3 ± 3.7	0.19	0.852
MMSE-K	VDG	22.9 ± 3.8	24.1 ± 3.8	3.00	0.004
	CG	23.8 ± 3.6	24.6 ± 3.9	2.42	0.019
25(OH)D (ng/mL)	VDG	14.0 ± 3.6	27.8 ± 8.2	11.38	< 0.001
	CG	13.3 ± 3.0	14.6 ± 7.2	1.25	0.218
Calcium (mg/dL)	VDG	9.2 ± 0.4	9.4 ± 0.3	4.68	< 0.001
	CG	9.3 ± 0.4	9.4 ± 0.4	1.26	0.214
Muscle mass (%)	VDG	34.2 ± 5.7	34.9 ± 4.9	1.55	0.129
	CG	35.9 ± 4.8	34.5 ± 4.7	- 3.04	0.004
GS (kg) Lt/Rt	VDG	17.6 ± 6.8	17.5 ± 6.6	- 0.06	0.950
	CG	17.8 ± 5.3	18.6 ± 5.0	1.60	0.117
	VDG	17.4 ± 6.7	17.8 ± 6.5	0.68	0.501
	CG	18.5 ± 4.6	19.0 ± 5.0	1.27	0.211
SB (sec)	VDG	7.3 ± 9.2	12.6 ± 16.5	2.18	0.035
	CG	11.2 ± 16.5	13.1 ± 14.3	0.81	0.420
TW (sec)	VDG	6.8 ± 10.3	4.2 ± 1.4	- 1.64	0.108
	CG	5.6 ± 2.9	6.3 ± 2.1	1.64	0.107
AF (cm) Lt Rt	VDG	26.8 ± 15.7	22.1 ± 13.2	- 3.44	0.001
	CG	25.6 ± 13.4	23.6 ± 11.5	- 1.47	0.149
	VDG	25.2 ± 15.3	20.9 ± 12.0	- 2.95	0.005
	CG	24.2 ± 13.2	21.1 ± 12.2	- 2.14	0.037

25(OH)D: serum 25-hydroxyvitamin D; AF: arm flexibility; CG: control group; GDSSF-K: geriatric depression scale short form-Korean version; GS: grip strength; Lt: left; MMSE-K: mini-mental state examination—Korean version; Rt: right; SB: static balance; SD: standard deviation; t^b: unpaired t-test between groups; TW: time to walk a standard course (4m); t^w: paired t-test within group; VDG: vitamin D supplementation group.

Table 4
Effects of vitamin D supplementation on depression, cognitive function, and physical function.

Variables	β	SE	p	Odds ratio (95% CI)
GDSSF-K	0.208	0.151	0.169	1.231 (0.916, 1.656)
MMSE-K	-0.192	0.121	0.114	0.826 (0.651, 1.047)
25(OH)D (ng/mL)	-0.174	0.041	< 0.001	0.841 (0.775, 0.911)
Calcium (mg/dL)	-0.541	0.753	0.473	0.582 (0.133, 2.547)
Muscle mass (%)	-0.301	0.123	0.014	0.740 (0.581, 0.941)
GS (kg)	-0.041	0.099	0.679	0.960 (0.791, 1.165)
SB (sec)	-0.007	0.021	0.726	0.993 (0.953, 1.034)
TW (sec)	0.339	0.134	0.012	1.403 (1.079, 1.825)
AF (cm)	-0.028	0.036	0.435	0.972 (0.907, 1.043)
Constant	1.668	0.465	< 0.001	

The reference category: Experimental group.
25(OH)D: serum 25-hydroxyvitamin D; AF: arm flexibility; GDSSF-K: geriatric depression scale short form-Korean version; GS: grip strength; MMSE-K: mini-mental state examination—Korean version; SB: static balance; SD: standard deviation; TW: time to walk a standard course (4m).

Recently, the effects of vitamin D on psychological problems as well as chronic diseases have been attracting attention. In Korea, 69.5% of elderly individuals require vitamin D supplementation.[19]

In our study, the baseline depression score was 5.8 in VDG and 5.2 in CG, indicating mild depression, consistent with previous studies, suggesting the need for depression intervention programs.[26] Depression scores were lower in overweight and obese adults after oral vitamin D supplementation (20,000 IU once weekly, for a year).[27] Furthermore, depression scores decreased in women taking 5,000 IU of vitamin D daily for 8 weeks.[28] In our study, depression was significantly reduced after treatment only in VDG. However, the difference between the two groups was not significant. It might be related to a limited number of sample sizes. Therefore, we suggest a study that enlarges the number of subjects.

Before treatment, cognitive function scores were slightly lower than normal values; after treatment, they increased to > 24 in both groups. Some studies report that higher vitamin D levels led to better cognitive function, while others report no correlation.[7,9] In this study, cognitive function remarkably increased in both groups, suggesting that this is a result of the exercise program; this is consistent with other findings stating that cognitive function can improve through interpersonal relationships formed while exercising.[29,30] We attempted to reduce the impact of exercise by conducting the program once a week. To better understand the effects of vitamin D supplementation on cognitive function, however, a follow-up study with supplementation alone is needed.

Participants' average serum vitamin D level was 13.6 ng/mL. A total of 34.8% of VDG participants and 33.3% of CG participants had severe vitamin D deficiency (< 12.0 ng/mL). The rate of vitamin D deficiency in our study was 67.5%, similar to that in another study, suggesting the need for supplementation.[19] Serum vitamin D levels in VDG increased more than those in CG, confirming the findings of other studies.[16,20]

Muscle mass ratio and time to walk a standard course also improved in VDG; this is consistent with other studies.[11,13] Since we did not measure whole-body muscle strength of participants, we could not clarify the causal relationship. Walking ability is related to independent physical activity. The effects of the exercise program cannot be entirely excluded. Future studies should compare the effects of the exercise program and vitamin D supplementation.

This study had some limitations. First, participants were recruited from senior centers in a city; elderly individuals not registered to a senior center were excluded. Second, we evaluated the effect of vitamin supplementation over a 12-week period; effects beyond this period were not investigated. Third, while vitamin D and calcium levels are influenced by dietary habits, they were not controlled for in the study. Fourth, the sample size is small.

Further studies should be conducted on elderly individuals living alone, who spend little time outdoors and do not visit a senior center, to test the effects of long-term vitamin D supplementation while also controlling effects of dietary habits. Future research should attempt a large sample and longer follow-up.

In conclusion, our findings demonstrate that vitamin D supplementation for 12 weeks improves vitamin D levels, muscle mass, and time to walk a standard course in vitamin D-deficient elderly individuals living alone. Our study provides basic data for further studies on factors affecting depression, cognitive function, and physical function in the increasing population of elderly individuals living alone in Korea.

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Declarations of interest

None.

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