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The Relationship Between Lower Vitamin D Levels and Hearing Loss in Older Adults

Yun Ji Lee[1*†], Jun Ho Jung[2*], and Jong Woo Chung[1]

[1]Department of Otorhinolaryngology-Head and Neck Surgery, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea
[2]University of Ulsan College of Medicine, Seoul, Korea

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Address for correspondence
Jong Woo Chung, MD, PhD
Department of Otorhinolaryngology-Head and Neck Surgery,
Asan Medical Center,
University of Ulsan
College of Medicine,
88 Olympic-ro 43-gil, Songpa-gu,
Seoul 05505, Korea
Tel +82-2-3010-3718
Fax +82-2-489-2773
E-mail jwchung@amc.seoul.kr

*These authors contributed equally to this work.

†Current affiliation:
Department of Otorhinolaryngology-Head and Neck Surgery,
Soonchunhyang University
College of Medicine, Seoul, Korea

Background and Objectives: Age-related hearing loss (ARHL) is a sensorineural disease that is associated with a number of factors. In addition to age, sex, environment, lifestyle, and comorbidities are all known to be related to ARHL as well. The prevalence of ARHL can be reduced by controlling the adjustable factors that cause it. Vitamin D levels are strongly related to calcium metabolism, which can affect ARHL. This study aimed to investigate the association between vitamin D and ARHL. **Subjects and Methods**: A total of 1,104 subjects aged >65 years were enrolled from the fifth Korean National Health and Nutrition Examination Survey, which was conducted from 2010–2012. Every participant received both an audiological assessment and a nutritional survey. The association between ARHL and serum vitamin D concentration was analyzed using logistic regression analyses with complex sampling adjusted for confounding factors such as alcohol consumption, smoking status, mobility, and bone mineral density. **Results**: Our multivariable analysis revealed that males in the group with lower serum levels of vitamin D (< 20 ng/mL) had a higher prevalence of ARHL (odds ratio, 1.638, 95% confidence interval, 1.058–2.538, *p*=0.027). **Conclusions**: This finding suggests that lower serum levels of vitamin D are associated with ARHL in the older male population.

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Keywords: Age-related hearing loss; Vitamin D; Bone mineral density; Mobility; Korean National Health and Nutrition Examination Survey.

Introduction

Age-related hearing loss (ARHL) is gradual, bilateral, and symmetrical sensorineural hearing impairment, which occurs when there is deterioration in the cochlea and related inner ear structures [1]. ARHL interrupts understanding and perception of speech, causing more serious problems such as depression and social isolation. Ultimately, ARHL affects physical, cognitive, and emotional function and leads to a decline in the patient's quality of life [2].

According to the recent large scaled study, 1 of 5 people are experiencing a large burden of hearing loss in the United States [3]. Aging population will be more affected by this condition in the future [3].

ARHL is an irreversible disease; therefore, identifying potential factors that may lower the risk of ARHL and making necessary adjustments to prevent its onset is of utmost importance. A variety of factors related to ARHL have been reported, such as aging, noisy environment, systemic disorder, and nutritional factor [2,4-6]. Among these factors, the nutritional aspect is easy to modulate for elderly people [7]. Emerging studies have emphasized the use of nutrient supplementation, such as vitamin A and B supplementation, for the purpose of preventing hearing loss [5].

Recently, several studies have revealed that the calcium metabolism has relationship with ARHL [8-13]. Osteoporosis is a systemic disorder caused by the imbalance between bone formation and resorption [11]. Osteoporosis is marked by reduced bone mineral density (BMD) and increased vulnerability of bones, primarily impacting the proximal femur and spine [11]. Osteoporosis also affects the bony structures of ear and otic capsule [8]. When those components have microfractures due to osteoporosis, hearing loss occurs [13]. Thus, modifying BMD can prevent ARHL [9]. Furthermore, a study reported that calcium regulates the force sensitivity of the hair cell transduction channel and amplifies sound stimuli [12].

Vitamin D plays an important role in correcting abnormal calcium metabolism [14]. Vitamin D facilitates absorption of calcium and phosphorus in the intestines [15]. The transcellular pathway is an active process to transport calcium that is highly regulated by vitamin D [14]. An adequate serum vitamin D level activates calcium transport, which prevents osteoporosis and maintains calcium homeostasis [4,12]. The relationship between calcium metabolism and ARHL has already been shown in many studies, but there are not many additional studies on the relationship between vitamin D and ARHL. In this study, we aimed to determine the potential impact of vitamin D status on ARHL using data from the fifth Korean National Health and Nutrition Examination Survey (KNHANES).

Subjects and Methods

Study participants

The KNHANES, a nationwide epidemiological study is conducted by the Korean Centers for Disease Control and Prevention under the Ministry of Health and Welfare, with annual Institutional Review Board (IRB) approval. Individuals are chosen randomly from districts within cities and provinces in South Korea among the chosen individuals, 80.8% of participants were involved in the fifth KNHANES from 2010 to 2012. There was a total of 25,534 participants, and the study included 10,152 participants aged over 50 years. Through the questionnaire, subjects with a history of head and neck cancer, chemotherapy, radiation therapy and workers in noisy environments were excluded. Among the 10,152 participants, 2,730 participants were excluded because either they did not have hearing test data or the difference in the dB level on a hearing test between each ear was greater than 15 dB. Then, 4,656 participants without serum vitamin D levels or BMD data were excluded from the analysis. Of the 2,766 participants, we planned to analyze the relationship between serum vitamin D and ARHL, we focused 1,104 participants who were older than 65 years old.

Otologic examination and audiologic evaluation

During the fifth KNHANES survey, otologic examinations were conducted by otolaryngology doctors by using a 4 mm, 0° endoscope (Xion GmbH, Berlin, Germany) to assess any anomalies associated with the eardrum or middle ear, such as retraction, otitis media with effusion, and cholesteatoma. Audiologic evaluation was conducted at 0.5, 1, 2, 3, 4, and 6 kHz in a soundproof booth. All participants underwent an otolaryngologic exam, and only those with normal tympanic membranes were included. ARHL was defined when the air conduction thresholds exceed an average of 25 dBs on pure tone audiometry at 0.5, 1, 2, and 4 kHz on both side of ears.

Definition of serum vitamin D deficiency

According to the Institute of Medicine, almost every individual has a serum vitamin D level of at least 20 ng/mL, which means that this level can be used as the definition of an adequate vitamin D status [16]. The clinical guideline defines vitamin D deficiency as having a level less than 20 ng/mL [17]. In a previous study analyzing the relationship between vitamin D and ARHL based on National Health and Nutrition Examination Survey (NHANES) data, the same cut-off was applied to vitamin D levels [4]. Based on these references, we also defined serum vitamin levels below 20 ng/mL as vitamin D deficiency in our study.

Quality of life assessment

The Euro Quality of Life-5 Dimension (EQ-5D) questionnaire is a commonly employed tool in Europe that can be used to assess generic quality of life and has been employed to investigate health-related quality of life (HRQoL) [18]. Each part of the EQ-5D (mobility, self-care, usual activities, pain/discomfort, and anxiety/depression) is measured with one question, and there are three possible answers (1=no problem, 2=moderate problem, 3=severe problem) [18]. The detailed descriptions of each response in the mobility section are as follows: "I have no problems walking about," "I have some problems walking about," and "I am confined to bed." This questionnaire has been also used to investigate HRQoL in Korea and is measured by the KNHANES [19]. It was noted that elderly Koreans with vitamin D deficiency were more prone to experiencing difficulties in terms of mobility, self-care, and their usual daily activities [19]. In this study, we used self-reported answers, specifically in dimension of "mobility," which was considered to have close association with vitamin D status and bone health, to evaluate relationship with ARHL.

BMD evaluation

The BMD of the total proximal femur, femoral neck, and lumbar spine was calculated by using dual-energy X-ray absorptiometry [20]. According to the World Health Organization, osteoporosis is diagnosed by T-score thresholds. A T score

≥-1.0 is considered normal. Osteopenia is defined when a T score falls within the range of -2.5 and -1.0. A T score below -2.5 is considered osteoporosis [21].

Statistical analysis

Univariate analyses were conducted to assess the association between serum vitamin D levels and hearing impairment, while multivariable logistic regression analyses were employed to investigate this association in a more comprehensive manner. Statistical methods were applied to account for the complex sampling design and the utilization of sampling weights from the fifth KNHANES. For categorical variables, data are displayed as the number of cases with a weighted percentage. The analyses were controlled for the subsequent potential confounding factors: age, sex, EQ-5D, smoking status, alcohol consumption, osteoporosis, and diabetes mellitus. Additionally, we performed a sex-stratified analysis for controlling significant confounding factor. The results of the logistic regression analyses are expressed as odds ratios (ORs) with 95% confidence intervals. A p value <0.05 was considered statistically significant. All statistical analyses were performed by SAS 9.4 (SAS Institute Inc, Cary, NC, USA).

Ethics statement

The study protocol for the analysis of the data was approved by the IRB of Asan Medical Center (2020-1753).

Results

The baseline characteristics of study participants are shown

Table 1. Baseline characteristics of the study participants

Characteristics	ARHL					
	No (n=453)			Yes (n=651)		
	N	Weighted N	Weighted %	N	Weighted N	Weighted %
Sex						
Male	182	436,916	37.80	329	810,801	47.65
Female	271	718,821	62.20	322	890,927	52.35
Alcohol consumption						
None	209	545,136	47.17	302	803,350	47.85
<1 (per month)	77	196,658	17.02	91	254,684	15.17
1–4 (per month)	72	166,887	14.44	114	294,372	17.53
2–3 (per week)	48	109,412	9.47	64	150,434	8.96
≥4 (per week)	47	137,645	11.91	70	176,206	10.49
Smoking						
Never	272	710,743	61.50	333	891,433	52.93
Former	131	320,044	27.69	208	525,055	31.18
Current	50	124,950	10.81	103	267,627	15.89
Diabetes						
No	362	919,336	79.55	525	1,398,612	82.19
Yes	91	236,401	20.45	126	303,116	17.81
Hypertension						
No	221	554,180	47.95	313	806,411	47.39
Yes	232	601,557	52.05	338	895,318	52.61
Mobility (EQ-5D)*						
No problem	308	745,789	64.57	364	901,099	53.45
Moderate problem	138	392,038	33.94	268	748,619	44.40
Severe problem	6	17,155	1.49	13	36,221	2.15
Serum vitamin D level (ng/mL)						
<20	265	650,764	56.31	398	1,041,338	61.19
≥20	188	504,973	43.69	253	660,391	38.81
BMD						
Normal	92	231,240	20.01	114	275,918	16.21
Osteopenia	211	541,045	46.81	298	731,737	43.00
Osteoporosis	150	383,452	33.18	239	694,073	40.79

*Numbers are less than group total because of missing data. ARHL, age-related hearing loss; EQ-5D, Euro Quality of Life-5 Dimension; BMD, bone mineral density in Table 1. The occurrence of ARHL was 58.97% (n=651) in the age group older than 65 years. ARHL occurred in 64.38% (n=329) of men and 54.30% (n=322) of women. When comparing the "mobility" of EQ-5D, subjects with ARHL had lower HRQoL than those without ARHL. Furthermore, those with ARHL were not likely to drink but were more likely to smoke than those without ARHL. In the ARHL group, ex-smokers accounted for 31.18% and current smokers 15.89%, whereas in the normal hearing group, the proportions were lower at 27.69% and 10.81%, respectively, showed lower proportions.

Table 2 shows an evaluation of factors associated with ARHL. In the univariate analysis, "moderate problems" in mobility according to the EQ-5D (*p*=0.003) showed an increased risk of ARHL. In addition, female sex (*p*=0.007) and "no problem" in mobility according to EQ-5D (*p*=0.009) were associated with a lower risk of ARHL on univariate analysis. In the multivariable analysis adjusted for age, sex, alcohol consumption, smoking status, diabetes, EQ-5D, BMD, and serum vitamin D level, "moderate problems" in mobility (EQ-5D) (*p*=0.005) and osteoporosis (*p*=0.015) were associated with a high risk of ARHL. Female subjects (*p*<0.001) and participants with "no problem" in mobility (EQ-5D) (*p*=0.019) showed a lower risk for ARHL on multivariable analysis.

As shown in Table 3, we studied whether men and women with low serum vitamin D levels differentially developed ARHL. In the univariate analysis, men with a "moderate problem" in mobility (EQ-5D) (*p*=0.001), osteopenia (*p*=0.033), and a low serum vitamin D level (*p*=0.045) had a higher risk of ARHL. Women showed a higher risk of ARHL when they had factors such as "moderate" problems in mobility (EQ-5D) (*p*=0.020) and osteoporosis (*p*=0.021). In the multivariable analysis, a low serum vitamin D level (*p*=0.027) and "moderate" problems in mobility (EQ-5D) (*p*=0.007) were significantly associated with a higher risk of ARHL in men; however, this finding was not significant in women. Additionally, we conducted propensity score matching analysis to adjust the age factor in each sex group (Table 4).

Before conducting matching, each group was divided into two subgroups based on vitamin D levels (<20 vs. ≥20 ng/mL).

Table 2. ORs of factors associated with ARHL

Factor	Univariate analysis		Multivariable analysis	
	OR (95% CI)	*p*	OR (95% CI)	*p*
Age	1.141 (1.098–1.186)	<0.001***	1.133 (1.090–1.177)	<0.001***
Sex				
Male	Reference		Reference	
Female	0.668 (0.499–0.893)	0.007**	0.303 (0.177–0.521)	<0.001***
Alcohol				
None	Reference		Reference	
<1 (per month)	0.879 (0.588–1.312)	0.526	0.984 (0.615–1.575)	0.946
1–4 (per month)	1.197 (0.782–1.833)	0.407	1.286 (0.817–2.024)	0.276
2–3 (per week)	0.933 (0.544–1.600)	0.800	0.745 (0.407–1.363)	0.338
≥4 (per week)	0.869 (0.552–1.366)	0.541	0.684 (0.399–1.173)	0.167
Diabetes				
No	Reference		Reference	
Yes	0.843 (0.584–1.217)	0.361	0.800 (0.540–1.186)	0.265
Mobility (EQ-5D)		0.009**		0.019**
No problem	Reference		Reference	
Moderate problem	1.580 (1.172–2.132)	0.003**	1.596 (1.150–2.216)	0.005**
Severe problem	1.747 (0.710–4.299)	0.223	1.578 (0.696–3.581)	0.274
Serum vitamin D level (ng/mL)				
≥20	Reference		Reference	
<20	1.224 (0.913–1.649)	0.176	1.300 (0.957–1.766)	0.092
BMD		0.115		0.051
Normal	Reference		Reference	
Osteopenia	1.133 (0.779–1.649)	0.511	1.326 (0.899–1.956)	0.155
Osteoporosis	1.517 (0.978–2.352)	0.063	1.888 (1.132–3.148)	0.015*

*p<0.05; **p<0.01; ***p<0.001. OR, odds ratio; ARHL, age-related hearing loss; CI, confidence interval; EQ-5D, Euro Quality of Life-5 Dimension; BMD, bone mineral density

Table 3. ORs of factors associated with ARHL in men and women

Factor	Men				Women			
	Univariate analysis		Multivariable analysis		Univariate analysis		Multivariable analysis	
	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*
Age	1.112 (1.052–1.176)	<0.001***	1.108 (1.049–1.172)	<0.001***	1.168 (1.114–1.225)	<0.001***	1.155 (1.098–1.214)	<0.001***
Alcohol								
None	1		1		1		1	
<1 (per month)	1.018 (0.479–2.164)	0.963	0.866 (0.380–1.974)	0.731	0.798 (0.494–1.289)	0.355	0.992 (0.560–1.757)	0.977
1–4 (per month)	0.910 (0.486–1.704)	0.767	1.108 (0.562–2.184)	0.767	1.097 (0.693–2.028)	0.768	1.393 (0.729–2.663)	0.315
2–3 (per week)	0.613 (0.324–1.159)	0.132	0.634 (0.323–1.247)	0.186	0.869 (0.271–2.790)	0.813	0.959 (0.317–2.903)	0.941
≥4 (per week)	0.565 (0.294–1.087)	0.087	0.663 (0.343–1.281)	0.220	0.743 (0.229–2.413)	0.620	0.523 (0.147–1.866)	0.317
Diabetes								
No	1		1		1		1	
Yes	0.963 (0.557–1.665)	0.891	0.715 (0.397–1.288)	0.263	0.822 (0.505–1.340)	0.431	0.823 (0.495–1.366)	0.449
Mobility (EQ-5D)								
No problem	1		1		1		1	
Moderate problem	2.615 (1.455–4.698)	0.001**	2.488 (1.283–4.825)	0.007**	1.574 (1.073–2.308)	0.020*	1.264 (0.821–1.945)	0.285
Severe problem	NE		NE		1.579 (0.500–4.991)	0.435	0.925 (0.338–2.530)	0.879
Serum vitamin D level (ng/mL)								
≥20	1		1		1		1	
<20	1.576 (1.010–2.461)	0.045*	1.638 (1.058–2.538)	0.027*	1.123 (0.711–1.773)	0.618	1.053 (0.651–1.704)	0.832
BMD								
Normal	1		1		1		1	
Osteopenia	1.620 (1.041–2.519)	0.033*	1.523 (0.956–2.425)	0.076	1.429 (0.579–3.527)	0.438	1.029 (0.413–2.561)	0.951
Osteoporosis	2.063 (0.952–4.470)	0.066	1.336 (0.591–3.021)	0.485	2.772 (1.166–6.590)	0.021*	1.641 (0.689–3.908)	0.262

*p<0.05; **p<0.01; ***p<0.001. OR, odds ratio; ARHL, age-related hearing loss; CI, confidence interval; EQ-5D, Euro Quality of Life-5 Dimension; BMD, bone mineral density

Table 4. Odds ratios of vitamin D level (<20 vs. ≥20 ng/mL) associated with ARHL in men and women after matching age

	Before matching				After age matching			
	Men		Women		Men		Women	
	<20 (n=273)	≥20 (n=238)	<20 (n=390)	≥20 (n=203)	<20 (n=226)	≥20 (n=226)	<20 (n=200)	≥20 (n=200)
Mean age (95% CI)	70.95 (70.38–71.51)	71.44 (70.81–72.07)	71.74 (71.14–72.34)	71.45 (70.70–72.19)	71.11 (70.56–71.66)	71.11 (70.56–71.66)	71.01 (70.42–71.59)	71.01 (70.42–71.59)
	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*
Crude	1.576 (1.010–2.461)	0.045	1.123 (0.711–1.773)	0.618	1.375 (0.915–2.066)	0.125	1.020 (0.693–1.500)	0.922
Adjusted	1.638 (1.058–2.538)	0.027	1.053 (0.651–1.704)	0.832	1.560 (0.946–2.574)	0.082	1.081 (0.711–1.644)	0.715

OR, odds ratio; ARHL, age-related hearing loss; CI, confidence interval

The mean age was about 71 years for all groups. After age matching, in the adjusted model of men and women, the ORs were 1.560 (p=0.082) and 1.081 (p=0.715), respectively.

Discussion

In this cross-sectional study, the relationship between serum vitamin D level and ARHL was investigated among the elderly. A low serum vitamin D level, defined as total vitamin D level <20 ng/mL, was associated with ARHL in elderly men who were the participants in the KNHANES. There was significant relationship even when other confounding variates were adjusted for. This finding is in accordance with that of previous studies that investigated the association between vitamin D, calcium, BMD, and hearing loss [4,22].

According to a recent cross-sectional study based on the same raw data, analyzing the association between age and hearing of Korean, it has been reported that there is a significant decrease in the threshold of high-frequency hearing with advancing age [23]. This decrease is particularly pronounced in patients aged 65 and above, showing a marked increase. In another prior study using KNHANES data, they considered patients aged 65 and above with bilateral hearing loss, referred to as ARHL [5]. As our study includes participants with a hearing difference of 15 dB or less between both ears, normal otoscopic findings, and excludes individuals with head and neck cancer, those undergoing cancer treatment, radiation exposure, and those working in noisy environments, although it was challenging to definitively discern sensorineural hearing loss through thorough bone conduction test results, we concluded that it would be appropriate to describe the participants as having ARHL.

In recent studies conducted in the United States, using data from NHANES, there have been reports indicating an association between vitamin D deficiency and hearing loss in the elderly population [4,24]. Our research findings, consistent with those results, elucidated the association between the risk of ARHL and low level of vitamin D among elderly Korean men. This study showed that men with an inadequate vitamin D status have an approximately 58% higher risk than men with an adequate vitamin D status. Even when adjusting for confounders, an insufficient vitamin D level in elderly men was associated with an approximately 64% higher risk than men with a sufficient serum vitamin D level.

The strength of this study is in the inclusion of a large number of individuals with adjustments for age, sex, systemic disease, and other confounding factors that are previously known as possible risk factors for ARHL. Furthermore, using audiometry data for elderly participants in the KNHANES is also a strength because self-reported hearing loss is not accurate enough [25]. In Table 4, to minimize the influence of age factors on the analysis results, additional propensity score matching analysis was conducted. While the statistical significance of our results diminished due to the reduction in sample size resulting from the procedure of comparing subjects with identical age profiles, our adjusted model for males did reveal a marginally significant association, demonstrating a consistent directional and magnitude trend in the ORs (1.560, $p=0.082$). Prior to matching, there was no significant difference in the age distribution according to the level of vitamin D (Table 4). Because we adjusted for this in our multivariable analysis, we believe it is appropriate to focus on these results as the primary outcome.

Osteoporosis and low calcium status have been known to cause hearing loss in the elderly in some clinical studies [1,8-10, 13]. Nutritional factors have been shown to be a cause of osteoporosis [14,26]. Vitamin D deficiency can interrupt calcium intake in the intestines, which can affect the balance between bone resorption and bone formation [11,14,20]. Systemic osteoporosis affects the middle ear bone and otic capsule which, as a result, impairs hearing function [9,13,27,28]. There was a suggestion that interactions between transforming growth factor β and vitamin D play a role in regulating osteoblasts, which could affect the mechanical characteristics of the cochlear bone and lead to sensorineural hearing loss [29,30]. Therefore, the potential mechanism by which vitamin D deficiency causes ARHL could have been related to bone metabolism.

Several research findings indicate that vitamin D could have an impact on hearing loss, specifically in the inner ears connected to the cochlea or the auditory nerve [24,31]. Mice lacking vitamin D receptors exhibit degenerative characteristics in the spiral ganglia and hair cells of the cochlea, leading to the development of gradual hearing impairment [32]. The proposed mechanisms center around vitamin D receptors in the auditory system, influencing calcium homeostasis in inner ear bones responsible for sound transduction, as well as affecting inner ear fluids, and hair cells [33].

Furthermore, changes in calcium homeostasis could be due to another mechanism [12,34]. Calcium entry through transduction channels leads to a fast negative movement in the mechanosensitive stereocilia of hair cells, which can amplify the signal in the cochlea [12]. In addition, calcium imbalances could accelerate oxygen-free radicals in hair cells and eventually lead to ARHL [34]. In summary, vitamin D deficiency may either have a direct impact on auditory function within the auditory organs or potentially lead to hearing loss through the dysregulation of calcium or bone metabolism.

In the results of this study, it was revealed that there was a correlation between ARHL and low vitamin D levels only in elderly men. According to a previous study, hearing loss appears to be more common in women in relation to metabolic syndrome [35]. In another study, there has been a reported significant association in women between hearing thresholds and visceral adipose tissue [36]. Considering factors such as sex-specific hormones and endocrine system that may influence auditory function, it is thought that further research taking into account these various factors is necessary.

As a cross-sectional epidemiological study, this study could not define causality between ARHL and vitamin D status. A number of KNHANES participants for whom vitamin D or BMD data were not available could not be enrolled in this analysis. Furthermore, variables, such as history of chronic kidney disease and head trauma that can affect ARHL and vitamin D status were not evaluated. The serum calcium, phosphorus, and parathyroid hormone level, which may potentially impact vitamin D levels, were not obtainable from the KNHANES data. As such, we acknowledge these as constraints to our research. Further studies with an adequate sample size that address possible confounding factors are needed.

In conclusion, this study shows epidemiological information that a low vitamin D level is associated with a risk of ARHL among men aged over 65 years. Men who are vitamin D deficient should be considered a risk group for ARHL compared with men with an adequate vitamin D status. Therefore, maintaining sufficient supplies of vitamin D in the elderly will help reduce the incidence of ARHL.

Conflicts of Interest

The authors have no financial conflicts of interest.

Author Contributions

Conceptualization: Jong Woo Chung. Data curation: Yun Ji Lee, Jun Ho Jung. Formal analysis: Jun Ho Jung. Investigation: Jun Ho Jung. Methodology: Jong Woo Chung. Project administration: Jong Woo Chung. Resources: Jong Woo Chung. Supervision: Jong Woo Chung. Validation: Yun Ji Lee. Visualization: Yun Ji Lee. Writing—original draft: Yun Ji Lee, Jun Ho Jung. Writing—review & editing: Yun Ji Lee. Approval of final manuscript: all authors.

ORCID iDs

Yun Ji Lee https://orcid.org/0000-0002-6238-1801
Jun Ho Jung https://orcid.org/0000-0002-0924-0102
Jong Woo Chung https://orcid.org/0000-0003-0765-9134

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