Nutr Res Pract. 2024 Dec;18(6):872-884
https://doi.org/10.4162/nrp.2024.18.6.872
pISSN 1976-1457·eISSN 2005-6168

Nutrition Research and Practice

Original Research

Check for updates

Development and validation of a semi-quantitative food frequency questionnaire as a tool for assessing dietary vitamin D intake among Korean women

Hye Ran Shin [1], **SuJin Song** [2], **and Sun Yung Ly** [1§]

[1]Department of Food and Nutrition, Chungnam National University, Daejeon 34134, Korea
[2]Department of Food and Nutrition, Hannam University, Daejeon 34054, Korea

Received: Jul 24, 2024
Revised: Oct 2, 2024
Accepted: Nov 11, 2024
Published online: Nov 26, 2024

§Corresponding Author:
Sun Yung Ly
Department of Food and Nutrition, Chungnam National University, 99 Daehak-ro, Yuseong-gu, Daejeon 34134, Korea.
Tel. +82-42-821-6838
Fax. +82-42-821-8968
Email. sunly@cnu.ac.kr

ORCID iDs
Hye Ran Shin
https://orcid.org/0000-0001-9434-7379
SuJin Song
https://orcid.org/0000-0003-1871-4346
Sun Yung Ly
https://orcid.org/0000-0001-6813-8573

Funding
This research was funded by the National Research Foundation of Korea Grant, funded by the Korean government (Ministry of Science and ICT), grant number 2020R1A2C1009608.

ABSTRACT

BACKGROUND/OBJECTIVES: Appropriate vitamin D status improves bone health and chronic diseases; it has shown benefits during the coronavirus disease 2019 pandemic. Therefore, assessing vitamin D status is crucial. However, limited research on vitamin D intake among Koreans complicates understanding of its consumption. This study aimed to develop and validate a semi-quantitative food frequency questionnaire (FFQ) to assess vitamin D intake among Koreans.
SUBJECTS/METHODS: A vitamin D FFQ was developed to include 31 vitamin D source foods from 8 food groups frequently consumed by Korean adults. The study included 152 women residing in a major city in South Korea. From September 2020 to August 2022, intake was surveyed using a 12-day dietary record (12-day DR) across 4 seasons, and 2 vitamin D FFQs were conducted approximately 9–11 months apart (FFQ1 and FFQ2). Reproducibility (FFQ1 vs. FFQ2) and validity (FFQ2 vs. 12-day DR) were verified using Spearman's rank correlation, weighted kappa coefficient, intraclass correlation, and Bland–Altman plots.
RESULTS: The vitamin D intake of Korean women using the newly developed vitamin D FFQ was higher at FFQ1 (4.90 μg/day) and FFQ2 (4.58 μg/day) compared with the 12-day DR (4.07 μg/day). Additionally, the results for reproducibility and validity were demonstrated through the Spearman's rank correlation coefficient (reproducibility, 0.592; validity, 0.460), weighted kappa coefficient (reproducibility, 0.379; validity, 0.284), intraclass correlation coefficient (reproducibility, 0.599; validity, 0.543), and Bland–Altman plots (reproducibility index, 3.95%; validity index, 3.95%).
CONCLUSION: This study confirmed the newly developed vitamin D FFQ is reliable and valid for assessing vitamin D intake among Korean women. These results suggest the FFQ is an effective tool for dietary assessment, particularly in large-scale studies where year-round monitoring may not be feasible. Further validation in Korean men is crucial to enhance its applicability, enabling significant contributions to assessing vitamin D intake among Korean adults.

Keywords: Vitamin D; diet record; Korea

Conflict of Interest
The authors declare no potential conflicts of interests.

Author Contributions
Conceptualization: Shin HR, Ly SY; Data curation: Shin HR; Formal analysis: Shin HR; Funding acquisition: Ly SY; Methodology: Shin HR, Song S, Ly SY; Project administration: Ly SY; Visualization: Shin HR; Writing - original draft: Shin HR, Song S, Ly SY; Writing - review & editing: Shin HR, Song S, Ly SY.

INTRODUCTION

Appropriate vitamin D status improves bone health and chronic diseases [1-4]; moreover, it has shown benefits during the coronavirus disease 2019 pandemic [5,6]. Therefore, assessing vitamin D status is crucial, especially in Korea, which has a population with vulnerable vitamin D nutritional status [7]. In Korea, despite the potential for vitamin D synthesis through ultraviolet-B (UV-B) exposure from sunlight, factors like ozone depletion and air pollution have curtailed outdoor activities and increased the use of UV-blocking tools, reducing adequate sunlight exposure [8,9]. Additionally, the UV-B radiation in winter is substantially lower than in summer, resulting in decreased vitamin D levels, highlighting the need for dietary vitamin D intake during this period [10].

Research on vitamin D intake among Koreans began recently after establishing a vitamin D content database for common Korean foods and re-analyzing surveys like the Korea National Health and Nutrition Examination Survey (KNHANES) [11-13]. Previous studies within the KNHANES used the 24-hour recall (24RC) method. The KNHANES employs a food frequency questionnaire (FFQ) and assesses all nutrients; however, it is less suitable for specific nutrients like vitamin D [14]. Compared with other methods, the 24RC method and dietary records (DRs) provide more accurate evaluations and are considered the gold standard in FFQ development; however, they are burdensome for year-round monitoring in large populations [14-16]. Many of the primary sources of vitamin D in the Korean diet are seasonal, necessitating time-consuming and costly annual surveys. Developing an FFQ to simplify the survey of vitamin D intake in Koreans could facilitate research on vitamin D nutritional status and lead to the development of necessary nutritional policies.

To the best of our knowledge, no tools have been developed to assess vitamin D intake exclusively among Koreans. The British Columbia Dairy Association created a calcium calculator that was the basis for the Canadian Calcium Assessment Tool [17]. Park *et al.* [18] adapted this tool to create the Korean Calcium Assessment Tool (KCAT), which includes 45 types of foods that are major sources of calcium and vitamin D according to the KNHANES data. Participants completed the KCAT and the KNHANES FFQ. While calcium intake assessments were consistent, vitamin D intake was overestimated. Jin *et al.* [19] updated the KCAT to reflect the major food sources of calcium and vitamin D, as shown in the KNHANES VI and VII (2013–2018). The updated KCAT showed consistent calcium assessments; however, vitamin D intake remained escalated. Because the KCAT included various major Korean vitamin D sources, such as fish, mushrooms, and fortified milk, the assessed vitamin D intake was about twice as high as that using the KNHANES FFQ, failing to validate its appropriateness. Therefore, a dedicated vitamin D assessment tool remains to be developed and tested against the 24RC reference method.

The FFQs for assessing vitamin D intake have been undertaken in various countries, including Ireland [20], Serbia [21], Libya [22], Qatar [23], England [24], Croatia [25], the United States [26,27], Finland [16], and Poland [28]. Vitamin D FFQs have been developed in various countries, reflecting local dietary patterns and policies. In Europe, vitamin D is primarily sourced from oily fish and fortified foods, with some countries mandating fortification in products like margarine and dairy [8,25,29]. FFQs from Poland and England illustrate regional differences, including various food groups such as animal products, cereals, and fats [24,28]. Unlike these countries, in Korea, the primary sources of vitamin D contributing to 99% of its intake are fish, eggs, dairy and milk products, meat, mushrooms, and cereals [12]. Cheese and butter consumption are not as prevalent in Korea; however, various fish and mushrooms are significant vitamin D sources. Moreover, Korea implements a voluntary fortification policy for vitamin D in foods, making fortified vitamin D products almost exclusively available in some dairy products, soymilk, and cereals. Owing to these distinct dietary patterns and policies, a vitamin D FFQ tailored for Koreans is necessary.

This study aimed to develop a semi-quantitative FFQ for assessing vitamin D intake, considering the dietary habits of Koreans, and initially focused on adult women to evaluate its appropriateness. The FFQ for vitamin D intake assessment was conducted in the same sample group twice, approximately 9–11 months apart, to evaluate its reproducibility. Furthermore, its validity was tested by comparing the results with those obtained from 12 days of DRs (12-day DRs) across the 4 seasons.

SUBJECTS AND METHODS

Development of an FFQ for assessing vitamin D intake

To develop an FFQ for evaluating vitamin D intake, this study reviewed vitamin D source foods consumed by adults aged 19 years and older from the 7th KNHANES (2016–2018) using 24RC results. The vitamin D content database was updated using previous research [12]. The FFQ food items were selected based on frequency and total intake, covering up to 90.99% of the cumulative intake (**Supplementary Table 1**). 'Bread' was excluded to prevent confusion owing to its typical inclusion of other vitamin D sources, such as meat or eggs. Fish roe and imitation crab meat were removed because of their minimal contribution (0.2%) to vitamin D intake. This resulted in identifying 25 frequently consumed foods, with eel, salmon, cereal, Spanish mackerel, quail eggs, and beef added, creating an FFQ with 30 items. Serving sizes for mushrooms, milk products, mayonnaise, and cereals were based on the 2020 Dietary Reference Intakes for Koreans (KDRIs) [30]. For fish, eggs, meat, and soymilk, serving sizes were set closer to those in the 2016 KNHANES FFQ [31]. For clarity, pictures of each serving size were shown. Food intake frequency was divided into 9 categories: 'almost never,' 'once a day,' '2 times a day,' '3 times a day,' '1–2 times a week,' '3–4 times a week,' '5–6 times a week,' 'once a month,' and '2–3 times a month.' The amount consumed per occasion was divided into 50%, 100%, and 200% of one serving.

In June 2020, a pilot study was conducted using the newly developed FFQ and a 3-day DR on 11 women in their twenties. Participants recorded their food and beverage intake over 3 non-consecutive days (2 weekdays and 1 weekend day). The comparison aimed to assess whether the items and portion sizes included in the FFQ accurately captured the participants' diet. The review of the 3-day DR and the FFQ indicated that soymilk, which was initially excluded, significantly contributed to vitamin D intake. Finally, the new FFQ was completed with 31 food items across 8 food groups (**Table 1**).

Study participants

Women in Daejeon were recruited through online social networks in 2 stages: the first included women aged between 19 and 29 years, and the second included women aged between 45 and 69 years. Participants met the inclusion criteria if they were able to participate throughout the year, had a body mass index (BMI) between 18 and 30 kg/m^2, had no chronic diseases, were not taking continuous medications, were not pregnant or breastfeeding, and consumed at least 2 regular meals per day. The first recruitment in

Table 1. List of food items included in the vitamin D FFQ

Food group	Food item	One serving[1)]	Vitamin D content (μg)[2)]
Fish	Anchovies (dried)	15 g	1.28
	Fermented fish	15 g	0.12
	Fish cakes	50 g	0.71
	Squid	75 g	0.23
	Shrimp	50 g	0.05
	Tuna	50 g	2.50
	Mackerel	50 g	2.60
	Pollock	50 g	0.24
	Croaker	50 g	4.21
	Hairtail	50 g	7.00
	Eel	50 g	11.70
	Salmon	50 g	16.00
	Spanish mackerel	50 g	3.50
Eggs	Egg	50 g	0.90
	Quail's eggs	50 g	1.50
Mushrooms	Shiitake mushroom	30 g	0.12
	Enoki mushroom	30 g	0.27
	King oyster mushroom oyster mushroom	30 g	0.23
	White mushroom	30 g	0.08
	Juda's ear mushroom	30 g	2.64
Meats and their products	Pork	200 g	1.34
	Processed meat	50 g	0.40
	Poultry	240 g	1.08
	Beef	200 g	0.60
Milk and dairy products	Milk	200 ml	0.40
	Yogurt		0.07
	Drinking yogurt	150 g	
	Regular yogurt	100 g	
	Cheese	20 g	0.09
	Ice cream	100 g	0.20
Pulses & legumes	Soy milk	200 mL	0.14
Oil & fats	Mayonnaise	5 g	0.02
Cereals	Cereal	30 g	3.43
Total of 8 food groups and 31 food items			

FFQ, food frequency questionnaire.
1)One serving size was defined from the 2020 Dietary Reference Intakes for Koreans for mushrooms, milk and its products, mayonnaise, and cereals and from the 2016 Korea National Health and Nutrition Examination Survey FFQ for fish, eggs, meat and its products, and soybean milk.
2)The vitamin D content (μg) per serving, utilized by the vitamin D database, was modified and supplemented in this laboratory based on previous research.

September 2020 involved 135 participants, and the second in September 2021 involved 148 participants, totaling 283. After excluding 32 participants who did not meet the criteria and 84 dropouts, 152 remained (67 from the first and 85 from the second recruitment). To ensure study reliability, 15 participants were excluded due to a more than 5-fold difference in vitamin D intake between FFQ1, FFQ2, and the 12-day DR records. The study was conducted from September 2020 to August 2021 for the first cohort and from September 2021 to August 2022 for the second cohort. This study was approved by the Chungnam National University Institutional Review Board (IRB) (approval numbers: 202005-BR-047-01, 202107-SB-130-01). Informed consent was confirmed by the IRB. The study was conducted in accordance with the Declaration of Helsinki and its later amendments.

Food intake survey

Participants recorded their dietary intake over 3 days in each season (Spring: March–May; Summer: June–August; Autumn: September–November; Winter: December–February), including 2 weekdays and 1 weekend day, totaling 12 days (12-day DR). The participants also completed the FFQ at the start of the research in autumn, the first season (FFQ1), and at the end in summer, the final season (FFQ2), in order to assess its reproducibility after a long interval. At the beginning of the study, participants were provided with an instructional video on how to complete the DRs and FFQ for self-recording. For the DRs, participants detailed the menu, ingredients, and amounts consumed and took photos of their meals before and after eating using a provided ruler. Experienced researchers collected all DRs and diet photos, and the nutrients consumed were calculated using a computer-aided nutritional analysis program (CAN pro, web version 5.0) [32] from the Korean Society of Nutrition. A vitamin D database was developed in a laboratory [12]. For the FFQ, this database was used to calculate food intake by multiplying the frequency of intake by the amount consumed.

Reproducibility and validity of the FFQ

The newly developed FFQ was validated for reproducibility and validity using Willett's method [14]. Reproducibility was verified by comparing the results of FFQ1 and FFQ2, administered approximately 9–11 months apart. Validity was assessed by comparing FFQ2 to the 12-day DR, as the FFQ2 included the period covered by the 12-day DR.

Statistical analyses

The age and anthropometrics of the study participants are presented as means ± SDs. Means, SDs, medians, and minimum and maximum values for the 12-day DR, FFQ1, and FFQ2 are provided, along with the percentage of participants meeting adequate intake levels in each survey. Differences among the 12-day DR, FFQ1, and FFQ2 groups were analyzed using the analysis of variance. The adequate vitamin D intake levels, according to the 2020 KDRIs, were used as the reference: 10 μg/day for those aged between 19 and 64 years and 15 μg/day for those aged 65 years and older [30].

The FFQ was validated using reproducibility assessment (FFQ1 vs. FFQ2) and validity assessment (FFQ2 vs. 12-day DR).

1) Because the vitamin D intake data from the FFQ1, FFQ2, and 12-day DRs did not follow a normal distribution, a non-parametric Spearman's rank correlation analysis was performed. The intra-class correlation coefficient (ICC) was also used to analyze the correlation and bias between the measurements, using Bland & Altman's reliability criteria [33,34]. To compare the vitamin D intake from each food group, as calculated from the FFQ2 and 12-day DRs, means and SDs are presented, and differences were analyzed using the Wilcoxon rank test. The correlation between the 2 variables was analyzed using Spearman's rank correlation coefficients.

2) Vitamin D intake from the 2 methods was categorized into quartiles, and the weighted kappa coefficient was calculated to evaluate concordance between the methods. The weighted kappa coefficient assigns weights based on the degree of disagreement [35]. According to Landis and Koch [36], values less than 0.20 indicate slight agreement, 0.21–0.40 fair agreement, 0.41–0.60 moderate agreement, 0.61–0.80 substantial agreement, and 0.81–1.0 almost perfect agreement [36].

3) To verify the agreement between the 2 survey methods, a Bland–Altman plot analysis was conducted using the means and differences in vitamin D intake measurements. The clustering of differences around the mean difference indicated a high level of agreement. The limits of agreement (LOA) were set at ± 1.96 times the SD of the differences (95%

confidence level), and the percentage of values outside this LOA was calculated as the Bland–Altman index [37]. Values up to a maximum of 5% were considered positive indicators [34]. Bland and Altman recommend a logarithmic transformation if larger values result in greater variability between measurements [33,34]. In this study, a logarithmic transformation was applied owing to the spreading pattern of mean values.

A *P*-value less than 0.05 was considered statistically significant. Statistical analyses were performed using IBM SPSS Statistics for Windows, version 28.0 (IBM Corp., Armonk, NY, USA) and MedCalc Statistical Software version 20.216 (MedCalc Software Ltd., Ostend, Belgium; https://www.medcalc.org; 2023).

RESULTS

Participant's age and anthropometrics

The study included 152 participants with an average age of 42.0 ± 17.4 years. The average weight was 57.8 ± 9.0 kg, and the average height was 160.1 ± 5.5 cm. The average BMI was 22.5 ± 3.3 kg/m^2 (**Table 2**).

Comparison of the vitamin D intakes assessed by the FFQs and the 12-day DR

The average daily vitamin D intake calculated from the FFQs and 12-day DR are presented in **Table 3**. The average daily vitamin D intake was higher in the FFQ1 at 4.90 ± 3.46 µg/day than in the FFQ2 at 4.58 ± 3.75 µg/day. The intake in the 12-day DR was the lowest at 4.07 ± 2.78 µg/day. Including vitamin D supplements, the average vitamin D intakes were 13.5 ± 17.5 µg/day for the FFQ1, 14.3 ± 19.7 µg/day for the FFQ2, and 12.6 ± 14.1 µg/day for the 12-day DR. The percentage of participants with vitamin D intake from only food sources below the adequate intake recommended by the 2020 KDRIs was 94.1% for the FFQ1, 97.4% for the FFQ2, and 96.1% for the 12-day DR. The percentage with total vitamin D intake, including supplements below the 2020 KDRIs, was 64.5% for the FFQ1, 61.8% for the FFQ2, and 61.8% for the 12-day DR.

Table 2. Participant's age and anthropometrics

Characteristic (n = 152)	Mean ± SD
Age (yrs)	41.95 ± 17.37
Weight (kg)	57.78 ± 9.04
Height (cm)	160.13 ± 5.47
BMI (kg/m^2)	22.53 ± 3.30

BMI, body mass index.

Table 3. Comparison of the vitamin D intakes assessed by FFQs and 12-day DR

Vitamin D Dietary Assessment	Vitamin D intake from food				Vitamin D intake from food and supplements			
	FFQ1	FFQ2	12-day DR	*P*-value[1)]	FFQ1	FFQ2	12-day DR	*P*-value[1)]
Mean ± SD (µg/day)	4.90 ± 3.46	4.58 ± 3.75	4.07 ± 2.78	0.121	13.43 ± 17.49	14.31 ± 19.71	12.55 ± 14.08	0.673
Median (µg/day)	3.95	3.64	3.30		6.20	6.44	7.27	
Minimum (µg/day)	0.90	0.85	0.75		0.90	0.85	0.85	
Maximum (µg/day)	20.92	35.69	14.57		113.28	128.32	66.58	
Percentage of intake less than AI level (%)[2)]	94.1	97.4	96.1		64.5	61.8	61.8	

FFQ, food frequency questionnaire; DR, dietary record; AI, adequate intake.
[1)] *P*-values were derived by the analysis of variance.
[2)] According to the 2020 Dietary Reference Intakes for Koreans, the AI of vitamin D is 10 µg/day for the 19–64 years age group and 15 µg/day for the ≥ 65 years age group.

Reproducibility and validity of the FFQ

The FFQ reproducibility and validity assessment results are presented in **Table 4**. The Spearman's rank correlation coefficient for reproducibility was 0.592 ($P < 0.001$), and for validity, it was 0.460 ($P < 0.001$). The ICC analysis showed that the reproducibility was 0.599, and the validity was 0.543, indicating moderate agreement. Analysis of quartiles for reproducibility showed that 38.82% of the participants were classified into exact agreement, 96.71% into the sum of exact and adjacent agreement, and 3.29% as the opposite. For validity, the analysis of quartiles showed that 37.50% of the participants were classified into exact agreement, 97.37% into the sum of exact and adjacent agreement, and 2.63% into opposite agreement. The weighted kappa coefficients for reproducibility and validity were 0.379 and 0.284, respectively, indicating fair agreement.

Reproducibility through Bland–Altman plots of the difference in vitamin D intake

Reproducibility was validated using a Bland–Altman plot (**Fig. 1**). The mean difference of the log-transformed values between the FFQ1 and FFQ2 was 0.07 µg, and the LOA ranged from −1.05 to 1.20. The Bland–Altman index was 3.95%.

Table 4. Validation of the FFQ, including assessment of reproducibility and validity

Validation methods	Reproducibility	Validity
	FFQ1 vs. FFQ2	FFQ2 vs. 12-day DR
Spearman's rank correlation		
Correlation coefficient	0.592	0.460
P-value	< 0.001***	< 0.001***
ICC[1)]	0.599	0.543
Analysis of quartile		
Exact agreement (%)	38.82	37.50
Exact agreement + adjacent (%)	96.71	97.37
Opposite (%)	3.29	2.63
Weighted kappa[2)]	0.379 (0.278–0.480)	0.284 (0.170–0.399)

FFQ, food frequency questionnaire; DR, dietary record; ICC, Intra-class correlation coefficient.
[1)]ICC of 0.4–0.6 indicates moderate agreement.
[2)]Weighted kappa coefficient of 0.21–0.40 indicates fair agreement.
***$P < 0.001$.

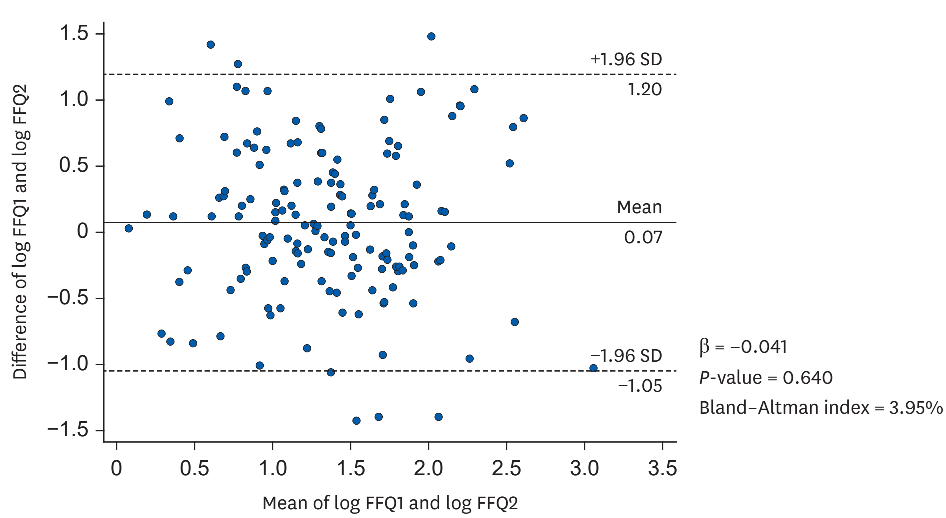

Fig. 1. Bland–Altman plot of FFQ reproducibility.
Values are log-transformed; lines are the mean difference and lower and upper 95% limits of agreement.
FFQ, food frequency questionnaire.

https://doi.org/10.4162/nrp.2024.18.6.872

Validity through Bland–Altman plots of the difference in vitamin D intake

Validity was assessed using a Bland–Altman plot (**Fig. 2**). The mean difference of the log-transformed values between the FFQ2 and 12-day DR was −0.11 μg, and the LOA ranged from −1.34 to 1.12. The Bland–Altman index was 3.95%.

Correlation between the FFQ2 and the 12-day DR in the major food groups for vitamin D

Table 5 presents the vitamin D intake values obtained from the FFQ2 and 12-day DR for the major vitamin D food groups. The food group with the highest vitamin D intake from both survey methods was the fish group (2.50 ± 3.51 μg/day and 2.27 ± 2.37 μg/day, respectively), and no significant differences were observed. Among other food groups, excluding fish, only the vitamin D intake from eggs was significantly higher in the 12-day DR results compared with the FFQ2 (0.87 ± 0.43 μg/day vs. 0.65 ± 0.53 μg/day, respectively; $P < 0.001$). The results from the FFQ2 were significantly lower for all other food groups than those for the 12-day DR. A significant positive correlation was observed between the 2 survey methods across all food groups. The highest Spearman's rank correlation coefficient was observed for the fish group (r = 0.498; $P < 0.001$), followed by milk and dairy products (r = 0.413; $P < 0.001$), pulses and legumes (r = 0.335; $P < 0.001$), and cereals (r = 0.316; $P < 0.001$).

DISCUSSION

Vitamin D is vital for managing immune-related disorders [38], cardiovascular diseases [39], and chronic degenerative diseases [1], highlighting its importance in nutritional status. Serum vitamin D levels are remarkably low among Koreans [7], and previous studies show that vitamin D intake is insufficient [11,12]. Because vitamin D intake from foods or supplements is a major factor that can influence serum vitamin D levels, developing a simple and accurate FFQ to assess vitamin D intake among Koreans is crucial.

In Korea, approximately 60% of the total vitamin D intake comes from fish [12], causing considerable day-to-day variation based on fish consumption. Moreover, 99% of daily vitamin

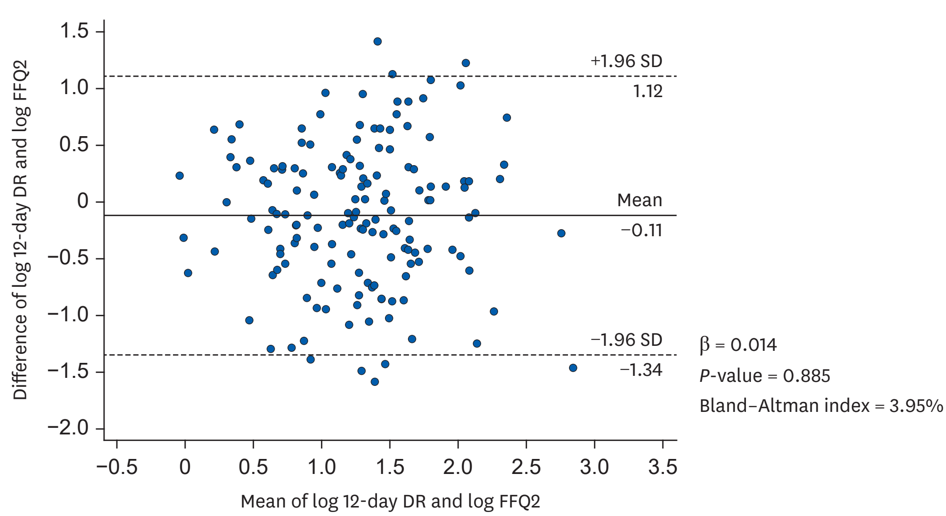

Fig. 2. Bland–Altman plot of FFQ validity.
Values are log-transformed; lines are the mean difference and lower and upper 95% limits of agreement.
DR, dietary record; FFQ, food frequency questionnaire.

https://doi.org/10.4162/nrp.2024.18.6.872

Table 5. Correlation between the FFQ2 and 12-day DR in the major food groups for vitamin D

Food group	Variable	Mean ± SD (μg/day)	*P*-value[1)]	Correlation coefficient[2)]	
				r	*P*-value
Fish	FFQ2	2.50 ± 3.51	0.555	0.498	< 0.001***
	12-day DR	2.27 ± 2.37			
Eggs	FFQ2	0.65 ± 0.53	< 0.001	0.290	< 0.001***
	12-day DR	0.87 ± 0.43			
Meats and their products	FFQ2	0.45 ± 0.39	< 0.001	0.291	< 0.001***
	12-day DR	0.26 ± 0.35			
Milk and dairy products	FFQ2	0.38 ± 0.39	< 0.001	0.413	< 0.001***
	12-day DR	0.14 ± 0.22			
Cereals	FFQ2	0.14 ± 0.33	0.002	0.316	< 0.001***
	12-day DR	0.10 ± 0.36			
Mushrooms	FFQ2	0.27 ± 0.42	< 0.001	0.181	0.026*
	12-day DR	0.08 ± 0.11			
Pulse & legumes	FFQ2	0.20 ± 0.39	< 0.001	0.335	< 0.001***
	12-day DR	0.07 ± 0.25			
Mayonnaise	FFQ2	0.00 ± 0.00	< 0.001	0.197	0.015*
	12-day DR	0.00 ± 0.01			

FFQ, food frequency questionnaire; DR, dietary record.
1)*P*-values were derived from the Wilcoxon-signed rank test.
2)Spearman's rank correlation.
**P* < 0.05; ****P* < 0.001.

D intake in Koreans is derived from 6 food groups: fish, eggs, meat, dairy, cereals, and mushrooms [12]. Serum vitamin D concentrations are lower in spring and winter when UV exposure is low; hence, the impact of vitamin D intake from food is essential during these periods [12]. Therefore, the FFQ method, which can assess annual food intake, is more appropriate for capturing nutrient intake such as vitamin D. The primary purpose of a FFQ is to assess long-term dietary patterns, making it suitable for obtaining data on the habitual intake of large populations over extended periods [14]. Because FFQs can be developed to reflect the dietary habits and cultural lifestyles of a specific population, they must be validated within the appropriate cohort [14,40].

In this study, we first verified the reproducibility of the newly developed FFQ by conducting 2 FFQ assessments approximately 9–11 months apart. Głąbska *et al.* [25] explored the applicability of an FFQ for assessing vitamin D intake among women in their 20s and 30s in Croatia. An FFQ was administered at 6-week intervals, which revealed a Spearman correlation of 0.80, ICC of 0.81, and weighted kappa of 0.62. Short intervals between measures can cause biased reproducibility. Differences between Głąbska's study and this study likely result from survey interval differences [14].

While most validation studies of existing vitamin D FFQs compared results with 3–4 days of DR, this study used 12 days of DR across 4 seasons. This approach may have increased variability in food intake; however, it was necessary to account for seasonal production changes of vitamin D source foods. A U.S. study with 123 athletes comparing 7-day DR and FFQ showed an insignificant Spearman's rank correlation coefficient (0.12), and the Bland–Altman plot results indicated the FFQ did not reflect DR well [27]. However, better validity of the FFQ developed in this study may be because of the limited variety of vitamin D source foods and fewer fortified foods consumed by Koreans, reducing individual variability [12]. Generally, nutrient intake assessments using FFQs tend to be higher than those using DRs, a phenomenon observed not only in vitamin D FFQ validation studies [20,23-25,27,28] but also in FFQ validations for various other foods and nutrients [41-43]. When participants recall the intake frequency of a limited number of foods through an FFQ, intake tends to be overestimated [14].

The newly developed FFQ showed a significant correlation with the 12-day DR for most food groups, especially fish and dairy, key sources of vitamin D in the Korean diet. This supports the FFQ's accuracy in estimating vitamin D intake from these food groups. While the FFQ accurately measured vitamin D intake from fish, it tended to overestimate it in other groups, which minimally impacted total vitamin D levels. The high correlation and consistency in fish group assessments highlight the FFQ's strengths given the predominant vitamin D intake from fish in Korean diets. Adjustments may be needed for food groups like 'meat and its products' and 'mushrooms,' where correlation was low. For eggs, higher vitamin D intake recorded in the 12-day DR than in the FFQ may be due to its unrecognized presence in processed foods like omelets, fried rice, toast, bread, and pastries. Therefore, explanations for processed foods containing eggs in the FFQ should be improved.

Based on this study, it was possible to further refine the food items in the previously developed FFQ to enhance its completeness. Among the food items included in the FFQ, those with very low consumption were shrimp, mayonnaise, and processed meats. Additionally, the number of food items for mushrooms could have led to an overestimation compared with the total vitamin D intake in this group (**Supplementary Table 2**). Therefore, the following 3 steps were proposed to reduce the number of vitamin D FFQ items and minimize the potential for overestimation: shrimp and mayonnaise should be removed from the food items; processed meats can be combined with pork into a single item; and for mushrooms, Juda's ear mushroom, which contains a high level of 8.8 μg of vitamin D per 100 g, and other mushrooms, which range from 0.3–0.9 μg/100g in vitamin D content, can be divided into 2 separate items (Juda's ear mushroom and mushrooms). As modified, the revised vitamin D FFQ now comprises 25 food items across 7 food groups (**Supplementary Table 3**). When the responses from our study were reanalyzed statistically in this way, the FFQ was validated, showing a Spearman's rank correlation coefficient of 0.445 (P < 0.001), ICC of 0.539, quartile opposite of 2.63%, weighted kappa of 0.274, and a Bland–Altman plot index of 4.0%, indicating reliability (data not presented).

The FFQ analysis showed fish significantly contributed to vitamin D intake in postmenopausal women, while younger women consumed a more diverse range of vitamin D sources (**Supplementary Fig. 1**). Despite these differences, the developed FFQ may be suitable for assessing vitamin D intake among Korean women of all ages.

This study has a few limitations. First, the study was conducted only among women; hence, additional research involving men is necessary. Previous studies suggest no significant difference between men and women regarding vitamin D sources, indicating the FFQ could also apply to men [12]. However, further validation in men is needed. Second, the 12-day DR results showed middle-aged women consumed significant amounts of vitamin D from supplements and beverages. Thus, it is essential to include an investigation on supplements and nutritional drinks when researching FFQs in relation to vitamin D biomarkers.

Despite these limitations, this study also has several strengths. It developed an FFQ specifically tailored to the dietary habits of Koreans, verified by comparison with DRs. The study used a 12-day DR over a year, considering seasonal variations, providing a more accurate picture of annual vitamin D intake patterns.

SUPPLEMENTARY MATERIALS

Supplementary Table 1

Accumulated contribution of vitamin D-rich foods in Korean adults by consumption and frequency

Supplementary Table 2

Vitamin D intake according to the 12-day DR and FFQs

Supplementary Table 3

The list of food items included in the revised vitamin D FFQ

Supplementary Fig. 1

Comparison of age groups in the FFQ2 and 12-day DR on the vitamin D-rich food groups. (A) Compares the mean vitamin D intake evaluated by the FFQ2 in the final version between young women and postmenopausal women, and (B) compares the mean vitamin D intake evaluated by the 12-day DR between young women and postmenopausal women.

REFERENCES

1. Gil Á, Plaza-Diaz J, Mesa MD, Vitamin D. Classic and novel actions. Ann Nutr Metab 2018;72:87-95. PUBMED | CROSSREF
2. Ceglia L. Vitamin D and its role in skeletal muscle. Curr Opin Clin Nutr Metab Care 2009;12:628-33. PUBMED | CROSSREF
3. Cantorna MT, Zhu Y, Froicu M, Wittke A. Vitamin D status, 1,25-dihydroxyvitamin D3, and the immune system. Am J Clin Nutr 2004;80:1717S-1720S. PUBMED | CROSSREF
4. Wimalawansa SJ. Vitamin D and cardiovascular diseases: causality. J Steroid Biochem Mol Biol 2018;175:29-43. PUBMED | CROSSREF
5. Wang Z, Joshi A, Leopold K, Jackson S, Christensen S, Nayfeh T, Mohammed K, Creo A, Tebben P, Kumar S. Association of vitamin D deficiency with COVID-19 infection severity: systematic review and meta-analysis. Clin Endocrinol (Oxf) 2022;96:281-7. PUBMED | CROSSREF
6. Demir M, Demir F, Aygun H. Vitamin D deficiency is associated with COVID-19 positivity and severity of the disease. J Med Virol 2021;93:2992-9. PUBMED | CROSSREF
7. Wahl DA, Cooper C, Ebeling PR, Eggersdorfer M, Hilger J, Hoffmann K, Josse R, Kanis JA, Mithal A, Pierroz DD, et al. A global representation of vitamin D status in healthy populations. Arch Osteoporos 2012;7:155-72. PUBMED | CROSSREF
8. EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA). Dietary reference values for vitamin D. EFSA J 2016;14:e04547. CROSSREF
9. Park JH, Hong IY, Chung JW, Choi HS. Vitamin D status in South Korean population: seven-year trend from the KNHANES. Medicine (Baltimore) 2018;97:e11032. PUBMED | CROSSREF
10. Kwak MK, Kim JH. The radiative characteristics of EUV-B over the Korean peninsula and exposure time for synthesizing adequate vitamin D. Atmosphere 2011;21:123-30. CROSSREF
11. You H, Shin HR, Song S, Ly SY. Vitamin D intake and bone mineral density in Korean adults: analysis of the 2009–2011 Korea National Health and Nutrition Examination Survey. Nutr Res Pract 2022;16:775-88. PUBMED | CROSSREF
12. Shin HR, Park HJ, Song S, Ly SY. Dietary vitamin D intake in low ultraviolet irradiation seasons is associated with a better nutritional status of vitamin D in Korean adults according to the 2013–2014 National Health and Nutrition Examination Survey. Nutr Res 2022;105:53-65. PUBMED | CROSSREF
13. Kim KN, Lee JS, Shim JS, Yoon MO, Lee HS. Estimated dietary vitamin D intake and major vitamin D food sources of Koreans: based on the Korea National Health and Nutrition Examination Survey 2016–2019. Nutr Res Pract 2023;17:451-63. PUBMED | CROSSREF

14. Kim S, Lee JS, Hong KH, Yeom HS, Nam YS, Kim JY, Park YK. Development and relative validity of semi-quantitative food frequency questionnaire for Korean adults. J Nutr Health 2018;51:103-19. CROSSREF
15. Willett W. Nutritional Epidemiology. Oxford: Oxford University Press; 2012.
16. Itkonen ST, Erkkola M, Skaffari E, Saaristo P, Saarnio EM, Viljakainen HT, Kärkkäinen MU, Lamberg-Allardt CJ. Development and validation of an interview-administered FFQ for assessment of vitamin D and calcium intakes in Finnish women. Br J Nutr 2016;115:1100-7. PUBMED | CROSSREF
17. BC Dairy Association. Calcium calculator™ [Internet]. Langley: BC Dairy Association; 2023 [cited 2023 August 15]. Available from: https://bcdairy.ca/calcium-calculator.
18. Park Y, Kim SH, Lim YT, Ha YC, Chang JS, Kim IS, Min YK, Chung HY. Validation of a new food frequency questionnaire for assessment of calcium and vitamin d intake in Korean women. J Bone Metab 2013;20:67-74. PUBMED | CROSSREF
19. Jin J, Lee Y, Park Y. Validation of the updated Korean calcium assessment tool. J Bone Metab 2021;28:325-32. PUBMED | CROSSREF
20. Weir RR, Carson EL, Mulhern MS, Laird E, Healy M, Pourshahidi LK. Validation of a food frequency questionnaire to determine vitamin D intakes using the method of triads. J Hum Nutr Diet 2016;29:255-61. PUBMED | CROSSREF
21. Djekic-Ivankovic M, Weiler HA, Nikolic M, Kadvan A, Gurinovic M, Mandic LM, Glibetic M. Validity of an FFQ assessing the vitamin D intake of young Serbian women living in a region without food fortification: the method of triads model. Public Health Nutr 2016;19:437-45. PUBMED | CROSSREF
22. Faid F, Nikolic M, Milesevic J, Zekovic M, Kadvan A, Gurinovic M, Glibetic M. Assessment of vitamin D intake among Libyan women - adaptation and validation of specific food frequency questionnaire. Libyan J Med 2018;13:1502028. PUBMED | CROSSREF
23. Ganji V, Abu-Dbaa R, Othman H, Zewein M, Al-Abdi T, Shi Z. Validation of vitamin D-specific food frequency questionnaire against food records for Qatari women. Foods 2020;9:195. PUBMED | CROSSREF
24. Watkins S, Freeborn E, Mushtaq S. A validated FFQ to determine dietary intake of vitamin D. Public Health Nutr 2021;24:4001-6. PUBMED | CROSSREF
25. Głąbska D, Uroić V, Guzek D, Pavić E, Bival S, Jaworska K, Giljević Z, Lange E. The possibility of applying the vitamin D brief food frequency questionnaire as a tool for a country with no vitamin D data in food composition tables. Nutrients 2018;10:1278. PUBMED | CROSSREF
26. Taylor C, Lamparello B, Kruczek K, Anderson EJ, Hubbard J, Misra M. Validation of a food frequency questionnaire for determining calcium and vitamin D intake by adolescent girls with anorexia nervosa. J Am Diet Assoc 2009;109:479-85, 485.e1-485.e3. PUBMED | CROSSREF
27. Larson-Meyer DE, Douglas CS, Thomas JJ, Johnson EC, Barcal JN, Heller JE, Hollis BW, Halliday TM. Validation of a vitamin D specific questionnaire to determine vitamin D status in athletes. Nutrients 2019;11:2732. PUBMED | CROSSREF
28. Głąbska D, Guzek D, Sidor P, Włodarek D. Vitamin D dietary intake questionnaire validation conducted among young Polish women. Nutrients 2016;8:36. PUBMED | CROSSREF
29. Whiting SJ, Calvo MS. Vitamin D fortification and supplementation policies to correct vitamin D insufficiency/deficiency globally. In: Feldman D, editor. Vitamin D. Amsterdam: Elsevier; 2018. p. 91-108.
30. The Korean Nutrition Society. Dietary Reference Intakes for Koreans 2020. Sejong: Ministry of Health and Welfare, The Korean Nutrition Society; 2020.
31. Ministry of Health and Welfare. Korea Health Statistics 2016: Korea National Health and Nutrition Examination Survey (KNHANES V-1). Cheongju: Korea Centers for Disease Control and Prevention; 2017.
32. The Korean Nutrition Society. Computer aided nutritional analysis program; can-pro 5.0 (web ver.) [Internet]. Seoul: The Korean Nutrition Society; 2022 [cited 2022 August 25]. Available from: http://canpro5.kns.or.kr.
33. Kong KA. Statistical methods: reliability assessment and method comparison. Ewha Med J 2017;40:9-16. CROSSREF
34. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Int J Nurs Stud 2010;47:931-6. CROSSREF
35. Szklo M, Nieto FJ. Epidemiology: Beyond the Basics. Burlington (MA): Jones & Bartlett Publishers; 2014.
36. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33:159-74. PUBMED | CROSSREF
37. Giavarina D. Understanding Bland Altman analysis. Biochem Med (Zagreb) 2015;25:141-51. PUBMED | CROSSREF
38. Charoenngam N, Holick MF. Immunologic effects of vitamin D on human health and disease. Nutrients 2020;12:2097. PUBMED | CROSSREF

39. Legarth C, Grimm D, Krüger M, Infanger M, Wehland M. Potential beneficial effects of vitamin D in coronary artery disease. Nutrients 2019;12:99. PUBMED | CROSSREF

40. Sierra-Ruelas É, Bernal-Orozco MF, Macedo-Ojeda G, Márquez-Sandoval YF, Altamirano-Martínez MB, Vizmanos B. Validation of semiquantitative FFQ administered to adults: a systematic review. Public Health Nutr 2021;24:3399-418. PUBMED | CROSSREF

41. Kim E, Kim M, Sohn C. Validity and reliability of a self-administered food frequency questionnaire to assess vitamin K intake in Korean adults. Clin Nutr Res 2016;5:153-60. PUBMED | CROSSREF

42. Kim JH, Kim OY, Lee MJ, Park E. Development and evaluation of semi-quantitative food frequency questionnaire for marriage migrant women in multicultural families. J Nutr Health 2021;54:76-94. CROSSREF

43. Mumu SJ, Merom D, Ali L, Fahey PP, Hossain I, Rahman AK, Allman-Farinelli M. Validation of a food frequency questionnaire as a tool for assessing dietary intake in cardiovascular disease research and surveillance in Bangladesh. Nutr J 2020;19:42. PUBMED | CROSSREF