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Vitamin D intake and mental health-related quality of life in older women: The Iowa Women's Health Study

Sarah Motsinger^a, DeAnn Lazovich^b, Richard F. MacLehose^c, Carolyn J. Torkelson^d, and Kim Robien^e

Sarah Motsinger: motsi002@umn.edu; DeAnn Lazovich: lazov001@umn.edu; Richard F. MacLehose: maci0029@umn.edu; Carolyn J. Torkelson: tork0004@umn.edu; Kim Robien: robie004@umn.edu

^{a,b,c,e}Division of Epidemiology and Community Health, School of Public Health, University of Minnesota, 1300 S. Second St., Suite 300, Minneapolis, MN 55454 USA

^cDivision of Biostatistics, School of Public Health, University of Minnesota, A460 Mayo Building, MMC 303, 420 Delaware St. S.E., Minneapolis, MN 55455 USA

^{b,e}Masonic Cancer Center, University of Minnesota, MMC 806, 420 Delaware Street SE, Minneapolis, MN 55455 USA

^dFamily Medicine and Community Health, University of Minnesota, MMC 381, 420 Delaware St SE, Minneapolis, MN 55455 USA

Abstract

OBJECTIVE—Vitamin D deficiency and mood disorders are both prevalent among the elderly. We evaluated the association between vitamin D intake and mental health-related quality of life (QOL) among elderly women participating in a large population-based study.

STUDY DESIGN—This study was a cross-sectional analysis of the Iowa Women's Health Study, a prospective study of cancer risk factors among post-menopausal women in Iowa that began in 1986. Additional survey data was collected from the cohort members in 1987, 1989, 1992, 1997, and 2004. Data for this analysis came from the 2004 questionnaire.

MAIN OUTCOME MEASURE—Mental health-related QOL was assessed using five scales from the Medical Outcomes Study 36-item short-form health survey. QOL scores were analyzed as continuous variables using linear regression, controlling for age, energy intake, BMI, education, smoking, living arrangement, antidepressant usage, comorbidity history, and physical activity.

RESULTS—Low vitamin D intake (<400 IU/day) was associated with poorer QOL scores compared to women with higher intake (≥400 IU/day). Differences in QOL scores by vitamin D intake group were attenuated with multivariable adjustment, but a significant overall association between vitamin D and QOL scores persisted. Further adjustment for physical activity attenuated all differences as well as the overall association between vitamin D and QOL scores.

CONCLUSIONS—Women who consumed <400 IU/day of vitamin D had significantly lower mental health-related QOL compared to those who consumed ≥400 IU/day. Meeting dietary vitamin D recommendations is a potential method for improving QOL among the elderly.

Corresponding author: Sarah Motsinger, MPH, Division of Epidemiology and Community, Health University of Minnesota, 1300 S. Second St., Suite 300, Minneapolis, MN 55454 USA, Phone: (217) 621-2210, Fax: (612) 624-0315, motsi002@umn.edu.
Reprint requests: Kim Robien, PhD, Division of Epidemiology and Community, Health University of Minnesota, 1300 S. Second St., Suite 300, Minneapolis, MN 55454 USA, Phone: (612) 625-8279, Fax: (612) 624-0315, robie004@umn.edu

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Keywords

Vitamin D; Quality of Life; Aged; Women's Health; Mental Health

1. INTRODUCTION

It has been estimated that one out of every four elderly adults lives with a mental illness such as depression or anxiety[1]. Increasingly, studies are suggesting a link between mental health and vitamin D status[2–4]. Several cross-sectional and descriptive studies have observed an association between serum 25-hydroxy vitamin D levels (25(OH)D) and presence of depressive symptoms in the elderly[5–7]. In addition, a prospective cohort study found that older women with low serum vitamin D (<20 ng/mL) had a significantly higher risk of developing depressive symptoms[8]. However, none of these studies examined the role of dietary and supplemental vitamin D intake.

A high prevalence of vitamin D deficiency has been reported in the elderly, even among those living in sunny climates, because of sunscreen usage and clothing coverage[9]. The ability of the skin to synthesize vitamin D endogenously after exposure to UVB light decreases with age, emphasizing the need for vitamin D exposure through dietary and supplemental intake[10]. The current recommended dietary allowance (RDA) for vitamin D for women over the age of 70 is 800 IU/day[11]. Sources of vitamin D, other than endogenous production, include dietary intake of animal products, fortified foods, and dietary supplements.

The aim of this study was to evaluate the association between dietary and supplemental vitamin D intake, in relation to the current RDA, and mental health-related QOL among elderly women. We hypothesized that elderly women with high dietary and supplemental vitamin D intake would be less likely to experience low mental health-related QOL compared to those who have low vitamin D intake.

2. MATERIALS AND METHODS

2.1 Study population

The Iowa Women's Health Study (IWHS) is a prospective cohort study started in 1986 to study cancer risk factors among post-menopausal women in Iowa. The methods for the study have been described in detail by Bisgard et al.. Briefly, a random sample of 99 826 women, aged 55 to 69 years, was selected from the Iowa driver's license list and mailed a self-administered questionnaire addressing anthropometrics, health history, lifestyle characteristics, sociodemographics, and dietary intake and supplement use. Of these women, 42% (N=41 836) completed and returned the baseline questionnaire, forming the IWHS cohort. On average, respondents were slightly younger, had lower body mass indices (BMI, kg/m²), and were more likely to live in rural areas[12]. The majority of respondents was non-Hispanic white (99%) and had completed high school or further education (87%).

Additional questionnaires were administered in 1987, 1989, 1992, 1997, and 2004. The 2004 survey reassessed dietary intake and supplement use, and also included the Medical Outcomes Study (MOS) 36-Item Short-Form Health Survey (SF-36)[13]. Of the original 41 836 participants, 20 844 of the 30 232 (68.9%) believed to be alive in 2004 completed and returned the questionnaire. Respondents were, on average, younger and had more education than non-respondents[14]. Women were eligible for this study if they responded to the 2004 questionnaire, were not currently receiving cancer-related therapy, and resided in Iowa(n=18 914). Women reporting a total daily calorie consumption of <600 kcal or >3500 kcal, or

who left 30 questions blank ($n=1599$) were excluded, as their data was likely to be unreliable or implausible[15]. Other exclusion criteria included incomplete SF-36 questions ($n=778$) or missing information for important confounders, such as antidepressant usage ($n=231$), living arrangement ($n=266$), education ($n=33$), BMI ($n=514$), or smoking ($n=388$). Exclusion categories were not mutually exclusive. After exclusions, a total of 15 954 women remained in the analysis.

2.2 Data collection

2.2.1 Exposure—Vitamin D intake from food and supplements in 2004 was obtained using a food frequency questionnaire (FFQ) developed by Willett and colleagues[16,17]. Participants reported their average consumption of food items over the past year. The questionnaire also assessed supplement intake of multivitamins and 18 individual supplements, including vitamin D. The 2004 questionnaire did not specify dosage information for vitamin D, therefore individual vitamin D supplements were assumed to provide 400 IU. The daily intake of nutrients from food was calculated using the Harvard Nutrient Database. Total vitamin D intake was defined as the combination of vitamin D consumed through multivitamins, individual supplements, and dietary intake. This FFQ has been shown to be reasonably reproducible and accurate among the older women participating in our study; vitamin D intake data obtained using the FFQ was highly correlated ($r=0.51$) with data obtained using 24-hour recalls in a subset of the IWH cohort[15]. Participants were grouped into categories based on vitamin D intake: <400 IU/day (less than half of the RDA), 400–799 IU/day, and ≥ 800 IU/day (met the RDA).

2.2.2 Outcome—Of the eight health concepts assessed by the SF-36, we examined the five scales that relate to mental health: mental health, role emotional, social functioning, vitality, and general health[18]. Questions addressed a participant's mental and/or physical health during the past four weeks as well as overall health perceptions. Our survey did not collect data specifically on clinical depression evaluations or diagnosis, however the mental health scale is the most sensitive to clinical manifestations of psychiatric conditions and measures anxiety, depression, loss of behavioral or emotional control, and psychological well-being[19]. The role emotional scale assesses role disability associated with mental health problems[19]. The social functioning scale measures the ability to engage in normal social activities[18]. The vitality scale assesses energy and fatigue, and the general health scale assesses overall health perceptions[13]. Each scale was standardized to age-specific population norms from 1998 using established algorithms[18], which utilized z-score standardization and norm-based transformation of each scale's z-scale[14]. The population average for each scale is a score of 50, and a change of one point represents 1/10 of a standard deviation (SD). A review of studies examining the minimally important difference (MID) for QOL measures found that the threshold of discrimination for determining differences in QOL is approximately 0.5 SD[20]. We created a dichotomous variable representing high and low mental health-related QOL split at 0.5 SD below the overall mean for each scale in order to examine MIDs in our population.

2.2.3 Other characteristics—BMI was calculated using self-reported height at baseline (1986) and self-reported weight in 2004, and was categorized based on established cut points: underweight (<18.5 kg/m²), normal weight (18.5–24.9 kg/m²), overweight (25–29.9 kg/m²), and obese (≥ 30 kg/m²). Physical activity was defined as a three-level variable (low, medium, high) based on a participant's answers to questions assessing moderate and vigorous physical activity on the 2004 questionnaire[21].

On each survey, participants were asked to report a diagnosis of diabetes, cardiovascular disease (including stroke or myocardial infarction), high blood pressure, rheumatoid arthritis,

or Parkinson's disease by a physician. Women were also asked if they had suffered a fracture that required treatment by a physician since age 20(baseline questionnaire) or the last questionnaire. Incident cancer diagnoses are determined through an annual linkage with the State Health Registry of Iowa, a member of the National Cancer Institute's Surveillance, Epidemiology, and End Results(SEER) program. A woman was considered to have a history of a disease if she had ever reported being diagnosed with that disease or if a cancer diagnosis was identified through SEER by the time of the 2004 follow-up.

2.3 Statistical Methods

Linear regression was used to estimate the association between total vitamin D intake category and mean QOL score for each of the five mental health-related scales, with the QOL scores treated as continuous measures. Potential confounding factors were included in multivariable models if the factor altered the QOL-vitamin D association by at least 10% after adjustment for age and energy intake, had biological relevance, or had previously been shown to be a risk factor for low QOL. The following factors were considered as potential confounders: alcohol consumption(g/day), total fat consumption(g/day), BMI category, education level(<high school, high school graduate or equivalent, postsecondary education), physical activity level(low, medium, high), smoking status(never, former, current smoker), current marital status(married, widowed, separated/divorced, single), current living arrangement(alone in home, with family in home, nursing home/assisted living home/other), antidepressant use(yes, no), and history of diabetes, high blood pressure, cardiovascular disease, rheumatoid arthritis, fractures, or cancer. Analysis of variance, a chi-square test, or Fisher's exact test was used to test differences in means or proportions of covariates by total vitamin D intake category using a two-sided *p*-value and alpha=0.05.

Marital status and current living arrangement were not independently associated with mental health-related QOL in this population($\chi^2=12.690$, $df=6$, $p<0.001$). Current living arrangement was a more significant predictor of QOL for all scales and altered the association between vitamin D intake and QOL more than marital status(data not shown). Therefore, we included living arrangement in the multivariable models.

Quality of life is a multidimensional concept, which includes assessment of physical limitations, and the ability to engage in regular physical activity is not an independent predictor of QOL for some of the scales. We present two multivariable models for all analyses in addition to a model based on good health behaviors relating to vitamin D consumption through supplements or healthy eating(Model 1). The first multivariable model included daily energy intake, age, smoking status, BMI category, education level, current living arrangement, antidepressant use, and histories of diabetes, cardiovascular disease, high blood pressure, fractures and cancer(Model 2). The second multivariable model adds physical activity as a covariate(Model 3). All analyses were repeated using the same models for each of the mental health-related QOL scales. We also analyzed the data stratifying by source of vitamin D exposure (supplements vs. diet), and found no substantial differences between our aggregated analyses. Thus, the aggregated analyses are presented here.

We tested the overall association of vitamin D(in tertiles) to each of the outcomes using multiple partial *F*-tests. All data was analyzed using SAS, Version 9.2(Cary, NC).

3. RESULTS

3.1 Study population characteristics

A total of 15 954 women(77% of total respondents) met the inclusion and exclusion criteria. Women excluded from the analysis did not differ with respect to vitamin D intake or

comorbidity history, but were on average, older, less educated, and more likely to live in an assisted living or nursing home(data not shown).

Women meeting the RDA for vitamin D for this age group(800 IU/day) were more likely to be normal weight, have completed postsecondary education, have a high level of physical activity, never have smoked, and to live with family in their home compared to women consuming less than the RDA(Table 1). Age and self-reported use of antidepressants was similar across the three vitamin D intake groups, as was history of rheumatoid arthritis and history of cancer. Self-reported history of diabetes and cardiovascular disease was highest in the lowest vitamin D intake group. Compared to women who did not report using vitamin D supplements, women who used vitamin D supplements were more likely to live with family in their home, less likely to be current smokers, and more likely to have completed postsecondary education. Supplement users were also more likely to be normal weight and to report a high level of physical activity. Fractures were more common among supplement users, while diabetes and cardiovascular disease were less common(data not shown).

The overall mean vitamin D intake in this population was 525.2 IU/day(SD=238), with only 18% of women meeting the RDA for women over the age of 70. This is a slight increase from the mean vitamin D intake for the cohort in 1986, which was 412.1 IU/day(SD=309). Vitamin D supplement use was reported by 11% of women in 1986 and 12% of women in 2004, and thus was consistent over time.

3.2 Vitamin D and poor mental health-related QOL

The proportion of women meeting the definition for poor mental health-related QOL was relatively similar(23–32%) across the five mental health-related scales and was highest in the lowest vitamin D intake group(Table 2). Among those with self-reported comorbidities, the highest prevalence of low mental-health related QOL scores was observed in the vitality scale and the general health scale. For all five scales, half of the women who reported using antidepressants had low mental health-related QOL scores.

3.3 Vitamin D and mean mental health-related QOL scores

After adjustment for age and daily energy intake(Model 1), women who consumed less than half of the RDA for vitamin D had significantly lower mean QOL scores for all scales compared to women in the middle and highest vitamin D intake groups(Table 3). There was no difference between the adjusted means for women in the middle and highest vitamin D intake group, except in the vitality scale, where women in the highest vitamin D intake group had a greater adjusted mean QOL score. For all scales, the overall association between vitamin D intake group and QOL score was statistically significant. The multivariable-adjusted means(Model 2) were attenuated, but differences similar to the age- and energy-adjusted model remained for the mental health and general health scales. A statistically significant overall association between vitamin D intake group and QOL score persisted for all scales after multivariable adjustment. The adjusted means for the social functioning, vitality, and general health scales did not differ by vitamin D intake group with further adjustment for physical activity(Model 3). Adding physical activity to the model also attenuated the overall association between vitamin D intake group and QOL score, and a significant association only remained for the mental health and social functioning scales.

4. DISCUSSION

4.1 Summary of findings

Our study found that women who consumed at least half of the RDA for vitamin D(400 IU/day) had slightly higher mental health-related QOL scores compared to women who

consumed less than half of the RDA. Additionally, there was a significant overall association between QOL scores and vitamin D intake group. These findings were consistent across all five components of mental health-related QOL: mental health, role emotional, social functioning, vitality, and general health.

4.2 Relationship between potential confounders

All associations were attenuated with multivariable adjustment. It is possible that some of the comorbid conditions lie on the causal pathway between vitamin D intake and QOL, and adjusting for these conditions biased our result towards the null. Adjustment for physical activity attenuated all differences between vitamin D intake groups. Previous studies have indicated an association between physical activity and the components of QOL related to physical health, suggesting that those with higher levels of physical activity also have higher QOL[22–24].

A review of vitamin D status and functional outcomes in the elderly found that supplementation with vitamin D reduced bone loss, improved muscle performance, and reduced the risk of falling [25]. A population-based study of older women in Sweden also observed that low vitamin D status was associated with a lower physical activity level, decreased gait speed, and decreased balance[26]. These results indicate that physical activity may lie on the causal pathway between vitamin D intake and QOL. Moreover, the vitality scale(which assesses energy and fatigue) is so closely related to physical activity that adjustment for physical activity may be inappropriate. A modest difference in QOL scores by vitamin D intake category persisted after adjustment for physical activity for the mental health and role emotional scales, which have greater sensitivity for evaluating mental health status.

4.3 Biological mechanism of vitamin D effects

Vitamin D is thought to be involved in brain health and function through multiple mechanisms. Vitamin D receptors(VDRs) in the cell's nucleus regulate the expression of target genes when bound to the active form of vitamin D(1,25-dihydroxyvitamin D). VDRs are expressed in areas of the brain important to behavioral regulation, including the cortex, cerebellum, and limbic system[27]. In animal models, mice with genetically impaired VDRs had abnormal brain shapes, decreased levels of neural growth factors, and exhibited behavioral aberrations including high anxiety, poor grooming, and poor social interaction[27].

4.4 Summary of current literature

The current literature is conflicting regarding the association between vitamin D and mood disorders[2], and few studies have examined the association in the elderly(Table 4). Several cross-sectional studies have found that vitamin D deficiency occurs concurrently with mood disorders in the elderly[5–7]. A randomized controlled trial in Norway and a prospective cohort study in Italy both found an association between vitamin D and mood disorders[8,28]. However, these findings are difficult to generalize because of the restricted study population[28] and selection bias due to loss to follow-up[8,28]. A recent study of elderly women also found an inverse association between vitamin D consumed through foods and occurrence of depressive symptoms[29].

To date, few studies have examined the relationship between vitamin D intake or status and QOL in elderly adults(Table 4). Two cross-sectional studies found that low serum 25(OH)D levels were associated with lower mental health-related QOL scores[30,31]. However, two randomized controlled trials found that vitamin D supplementation did not improve QOL scores[32,33]. These findings are difficult to interpret as they were restricted to disease-

specific populations[30,31,33], excluded participants with poor health[32], or had small sample sizes[30,33,34].

4.5 Strengths, limitations, and future directions

Our study included women with a variety of health conditions, including cardiovascular disease, cancer, and diabetes. Thus we are able to assess the association between vitamin D and mental health-related QOL, independent of disease status. Other strengths of our study include its large sample size and the assessment of both dietary and supplemental vitamin D intake. We were also able to reduce potential variability in sun exposure by location through restricting our study population to a small geographical area. Furthermore, our study included assessment and adjustment for important factors that may alter the association between vitamin D and mental health such as education level, smoking status, BMI, living arrangement, and antidepressant use.

Because our study was cross-sectional, we cannot infer causality between vitamin D intake and mental health-related QOL. The homogeneity of the study population is another limitation as participants were mostly Caucasian, female, and similar in age. Women who returned the completed 2004 questionnaire were younger than non-respondents[14]; consequently, a possibility of survival bias exists as women had to survive until the 2004 follow-up and be healthy enough to complete the survey. A possibility of misclassification with respect to vitamin D status exists because we had no assessment of UV exposure and did not conduct serum 25(OH)D assays. In addition, despite adjusting for comorbidities and other relevant demographic and lifestyle factors, we cannot rule out the possibility that our findings are due to unmeasured variables or residual confounding. Future studies should evaluate dietary and supplemental vitamin D intake along with serum 25(OH)D assays and UV exposure assessment in order to reduce misclassification. A prospective cohort study with repeated measures of vitamin D status and mental health-related QOL would be necessary to account for seasonal variation in UV exposure and mood, and would be able to test a causal association between vitamin D status and QOL.

4.1 CONCLUSION

Understanding QOL among the elderly is increasing in importance, as the number of persons aged 60 years is predicted to exceed 1.2 billion by the year 2020[35]. Finding methods for reducing the morbidity and mortality associated with mental illness is essential for improving the health of the elderly. In our population, the majority(82%) of women did not consume the RDA for vitamin D. Consuming 400 IU of vitamin D per day was associated with higher mental health-related QOL scores compared to those who consumed less than 400 IU/day. Vitamin D may also be involved in other physiologic processes, such as susceptibility to falls[36], fractures[37], diabetes[38], cancer[39], and infectious[40] and cardiovascular diseases. [41]. Therefore, meeting dietary recommendations for vitamin D intake is a potential method for improving overall health in older women.

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Abbreviations

QOL	Quality of Life
25(OH)D	25-Hydroxy vitamin D

MOS	Medical Outcomes Study
SF-36	36-item Short-Form Health Survey
SF-12	12-item Short-Form Health Survey
VDR	Vitamin D Receptor
RDA	Recommended Dietary Allowance
IWHS	Iowa Women's Health Study
MID	Minimally Important Difference
BMI	Body mass index
SEER	Surveillance, Epidemiology, and End Results program

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Table 1Study population characteristics by total vitamin D intake. Iowa Women's Health Study, 2004. (N=15 954)^f

	Total Vitamin D Intake			<i>p-value</i> ²
	<400 IU/day (n=5846)	400–799 IU/day (n=7241)	800 IU/day (n=2867)	
Mean Vitamin D intake	198 (103)	582 (103)	1049 (224)	
Any Supplement Use	5755 (98.4%)	7154 (98.8%)	2847 (99.3%)	0.003
Vitamin D from any supplement	858 (8.3%)	6649 (64.4%)	2823 (27.3%)	<0.001
Age	79.2 (4)	79.1 (4)	79.1 (4)	0.11
Total energy intake (kcal/day)	1814 (677)	1929 (686)	2217 (766)	<0.001
BMI (kg/m ²)				<0.001
< 18.5	160 (2.7%)	173 (2.4%)	61 (2.1%)	
18.5–25	2081 (35.6%)	2865 (39.6%)	1244 (43.4%)	
25–30	2118 (36.2%)	2593 (25.8%)	1056 (36.8%)	
>30	1487 (25.4%)	1610 (22.2%)	506 (17.7%)	
Education ³				<0.001
<High School	1002 (17.1%)	901 (12.4%)	363 (12.7%)	
=High School	2570 (44.0%)	3125 (43.2%)	1113 (38.8%)	
>High School	2274 (38.9%)	3215 (44.4%)	1391 (48.5%)	
Activity level				<0.001
Low	3057 (52.8%)	3175 (44.3%)	1066 (37.6%)	
Medium	1560 (27.0%)	2123 (29.6%)	834 (29.4%)	
High	1171 (20.2%)	1875 (26.1%)	939 (33.1%)	
Smoking status				0.004
Never	4077 (69.7%)	5109 (70.6%)	2043 (71.3%)	
Former	242 (4.1%)	252 (3.5%)	72 (2.5%)	
Current	1527 (26.1%)	1880 (26.0%)	752 (26.2%)	
Marital Status				0.26
Married	2704 (46.3%)	3356 (46.4%)	1353 (47.2%)	
Widowed	2790 (47.7%)	3476 (48.0%)	1348 (47.0%)	
Separated/Divorced	215 (3.7%)	259 (3.6%)	119 (4.2%)	
Never married	137 (2.3%)	149 (2.1%)	46 (1.6%)	
Current living arrangement				<0.001
Alone in home	2570 (44.0%)	3298 (45.6%)	1294 (45.1%)	
With family in home	2828 (48.4%)	3526 (48.7%)	1423 (49.6%)	
Assisted living/Nursing home/Other	448 (7.7%)	417 (5.8%)	150 (5.2%)	

	Total Vitamin D Intake			<i>p-value</i> ²
	<400 IU/day (n=5846)	400–799 IU/day (n=7241)	800 IU/day (n=2867)	
Antidepressant use	597 (10.2%)	763 (10.5%)	321 (11.2%)	0.37
History of Diabetes	502 (8.6%)	549 (7.6%)	178 (6.2%)	<0.001
History of High blood pressure	1741 (29.8%)	2018 (27.9%)	714 (24.9%)	<0.001
History of Cardiovascular disease	914 (15.6%)	1056 (14.6%)	390 (13.6%)	0.03
History of Rheumatoid arthritis	572 (9.8%)	668 (9.2%)	272 (9.5%)	0.55
History of Fractures	1626 (27.8%)	2041 (28.2%)	865 (30.2%)	0.07
History of Cancer	846 (14.5%)	1064 (14.7%)	393 (13.7%)	0.44

¹Values are Mean (SD) or N (%).

²*P*-values (two-sided) were calculated using one-way ANOVA for continuous variables and a χ^2 test or Fisher's exact test for categorical variables.

³From baseline (1986) survey.

Table 2

Prevalence of Poor Quality of Life Outcomes¹, by vitamin D status, comorbidities, and antidepressant use. Iowa Women's Health Study, 2004. (n=15 954)²

Covariate	Poor Mental Health	Poor Role Emotional	Poor Social Functioning	Poor Vitality	Poor General Health
Overall (no covariate stratification)	3848 (24.1%)	3634 (22.8%)	3900 (24.5%)	5084 (31.9%)	4399 (27.6%)
Vitamin D category					
<400 IU/day	1525 (26.1%)	1433 (24.5%)	1519 (26.0%)	1969 (33.7%)	1770 (30.3%)
400-799 IU/day	1673 (23.1%)	1559 (21.5%)	1708 (23.6%)	2257 (31.2%)	1905 (26.3%)
800 IU/day	650 (22.7%)	642 (22.4%)	673 (23.5%)	858 (29.9%)	724 (25.3%)
Diabetes	422 (34.3%)	423 (34.4%)	501 (40.8%)	616 (50.1%)	593 (48.3%)
High Blood Pressure	1250 (28.0%)	1310 (29.3%)	1384 (30.9%)	1735 (38.8%)	1623 (36.9%)
Cardiovascular disease	791 (33.5%)	773 (32.8%)	895 (37.9%)	1133 (48.0%)	1110 (47.0%)
Fractures	1180 (26.0%)	1161 (25.6%)	1284 (28.3%)	1565 (34.5%)	1359 (30.0%)
Cancer	566 (24.6%)	563 (24.5%)	626 (27.2%)	809 (35.1%)	744 (32.3%)
Antidepressant Users	951 (56.6%)	815 (48.5%)	841 (50.0%)	976 (58.1%)	847 (50.4%)

¹ Poor QOL defined as a QOL score of less than 0.5 SD below the overall mean for each scale.

² Data are n (%).

Table 3

Mental Health-Related Quality of Life Scores Least-Squares Means and Standard Errors by Vitamin D status. Iowa Women's Health Study, 2004. (N=15,954)¹

	Total Vitamin D Intake			Multiple Partial F-test <i>p</i> value
	<400 IU/day (n=5846)	400–799 IU/day (n=7241)	800 IU/day (n=2867)	
Mental Health				
Model 1: Age- and Energy-Adjusted	51.7 ± 0.1 ^a	52.5 ± 0.1 ^b	52.8 ± 0.2 ^b	<0.001
Model 2: Multivariable Adjusted ²	45.4 ± 0.2 ^a	45.9 ± 0.2 ^b	46.1 ± 0.2 ^b	<0.001
Model 3: Model 2 + Physical Activity ³	46.4 ± 0.2 ^a	46.8 ± 0.2 ^b	46.9 ± 0.3 ^b	0.002
Role Emotional				
Model 1: Age- and Energy-Adjusted	47.2 ± 0.1 ^a	48.1 ± 0.1 ^b	48.0 ± 0.2 ^b	<0.001
Model 2: Multivariable Adjusted ²	40.2 ± 0.3 ^a	40.8 ± 0.3 ^b	40.5 ± 0.3 ^{ab}	0.006
Model 3: Model 2 + Physical Activity ³	41.7 ± 0.3 ^a	42.1 ± 0.3 ^b	41.7 ± 0.3 ^{ab}	0.50
Social Functioning				
Model 1: Age- and Energy-Adjusted	49.0 ± 0.1 ^a	49.6 ± 0.1 ^b	49.9 ± 0.2 ^b	<0.001
Model 2: Multivariable Adjusted ²	40.9 ± 0.3 ^a	41.3 ± 0.3 ^b	41.3 ± 0.3 ^{ab}	0.002
Model 3: Model 2 + Physical Activity ³	43.0 ± 0.3 ^a	43.1 ± 0.3 ^a	42.8 ± 0.3 ^a	0.04
Vitality				
Model 1: Age- and Energy-Adjusted	48.9 ± 0.1 ^a	49.4 ± 0.1 ^b	49.9 ± 0.2 ^c	<0.001
Model 2: Multivariable Adjusted ²	42.1 ± 0.3 ^a	42.2 ± 0.3 ^a	42.5 ± 0.3 ^a	0.04
Model 3: Model 2 + Physical Activity ³	44.8 ± 0.3 ^a	44.5 ± 0.3 ^a	44.4 ± 0.3 ^a	0.28
General Health				
Model 1: Age- and Energy-Adjusted	47.3 ± 0.1 ^a	48.0 ± 0.1 ^b	48.5 ± 0.2 ^b	<0.001
Model 2: Multivariable Adjusted ²	39.3 ± 0.2 ^a	39.6 ± 0.2 ^b	39.8 ± 0.3 ^b	<0.001
Model 3: Model 2 + Physical Activity ³	41.6 ± 0.2 ^a	41.6 ± 0.2 ^a	41.5 ± 0.3 ^a	0.87

¹ Comparisons are pairwise within a row. Means that do not share a letter are significantly different ($p < 0.05$).

² Adjusted for age, daily energy intake (kcal), BMI (<18.5, 18.5–24.9, 25–29.9, 30 kg/m²), living arrangement (alone in home, with family in home, assisted living/nursing home/other), smoking status (current, former, never), education (less than high school, high school graduate or equivalent, post-secondary education), antidepressant use (yes, no), history of diabetes (yes, no), history of cancer (yes, no), history of high blood pressure (yes, no), history of cardiovascular disease (yes, no), history of fractures (yes, no).

³ Physical Activity (low, medium, high); N=15,800.

Table 4
Summary of current literature regarding vitamin D and mood disorders and quality of life in the elderly.

Author (year)	N	Study Population	Study Design/Procedures	Outcome Assessment	Findings/Notes
Mood disorders					
Bertone-Johnson et al. (2011)[29]	81189	Participants in the Women's Health Initiative, aged 50–79 years	Cross-sectional and Prospective analysis <i>Exposure:</i> Dietary and supplemental vitamin D intake	Bumam 8-item scale for depressive disorders assessed at baseline and 3 year follow-up	Inverse association between vitamin D consumed through foods and occurrence of depressive symptoms.
Hoogendijk et al. (2008)[5]	1282	Population-based cohort aged 65–95 years from the Netherlands	Cross-sectional <i>Exposure:</i> Serum 25(OH)D levels	Center for Epidemiologic Studies-Depression Scale (CES-D) and Diagnostic Interview Schedule	Serum 25(OH)D levels were 14% lower in persons with minor depression or major depressive disorder compared with nondepressed persons ($p<0.001$). Depression severity (measured by CES-D) was significantly associated with decreased serum 25(OH)D levels ($p=0.03$).
Jorde et al. (2008) [28]	334	Overweight and obese participants aged 21–70 years from Norway recruited for a weight loss study	Randomized Controlled Trial <i>Treatment:</i> 20,000 or 40,000 IU vitamin D per week for 1 year <i>Placebo:</i> Placebo capsules	Beck Depression Inventory score and subscales assessed at baseline and end of the study (1 year)	Excluded participants using antidepressants or with history of coronary infarction, angina pectoris, stroke, renal stone disease, or diabetes. Possible selection bias: 24.3% of participants lost to follow-up. Both of the treatment groups showed a reduction in depressive symptoms after vitamin D supplementation for one year, while the placebo group showed no significant change in depressive symptoms.
Milaneschi et al. (2010)[8]	639	Participants from the InCHIANTI (Invecchiare in Chianti, aging in the Chianti area) Study, a prospective population-based study of older persons (65 years) in Tuscany (Italy)	Prospective Cohort Study <i>Exposure:</i> Serum 25(OH)D levels	Center for Epidemiologic Studies-Depression Scale (CES-D); assessed at baseline, 3-year follow-up, and 6-year follow-up	Possible selection bias: 15.9% of participants lost to follow-up. Women (N=298) with low vitamin D (<20 ng/mL) at baseline had significantly higher risk of developing depressive mood over the follow-up (hazard ratio=2.0; 95% CI: 1.2–3.2; $P=0.005$).
Stewart et al. (2009)[7]	2070	Nationally representative general population sample of English people aged 65 years, living in private households	Cross-Sectional <i>Exposure:</i> Serum 25(OH)D levels	10-item Geriatric Depression Scale (GDS10)	Depressive symptoms were associated with clinical vitamin D deficiency (<10 ng/mL) after adjustment for other covariates (OR=1.45, 95% CI: 1.02–2.08).
Wilkins et al. (2006)[6]	80	Community-dwelling, ambulatory older adults (>60 years) from the St. Louis metropolitan area with and without mild Alzheimer's disease	Cross-sectional <i>Exposure:</i> Serum 25(OH)D levels, grouped into 3 categories: vitamin D sufficient (20 ng/mL), insufficient (10–19.9 ng/mL), and deficient (<10 ng/mL)	Depression Symptoms Inventory, Clinical diagnosis of a mood disorder	Excluded participants who used prescription vitamin D supplements or nonprescription vitamin D greater than 800 IU per day. Fifty-eight percent of participants had vitamin D levels below the sufficient range. Compared to those who had sufficient serum vitamin D levels, those who were deficient had 11.69 times the odds of a current mood disorder (95% CI: 2.04–66.86) and those who had insufficient vitamin D levels had an odds ratio of 2.54 (95% CI: 0.63–10.51), after adjustment for age, sex, race, and season of vitamin D assessment.
Quality of life					

Author (year)	N	Study Population	Study Design/Procedures	Outcome Assessment	Findings/Notes
Dunville et al. (2006)[32]	1621	Women aged 70 years from three areas of the UK	Randomized Controlled Trial <i>Treatment:</i> 1000 mg calcium + 800 IU vitamin D for 6 months, Information sheet and follow-up visits <i>Placebo:</i> Information sheet	Medical Outcomes Study 12-item short-form health survey	Participants were excluded if they had a personal or family history of fractures, were current smokers, or reported poor health. Did not take baseline vitamin D status into account, and did not control for risk factors for low QOL. No improvement in mental health scores with vitamin D supplementation.
Anand et al. (2011) [30]	192	Incident dialysis patients involved with the nutrition substudy of the Comprehensive Dialysis Study	Cross-sectional <i>Exposure:</i> 25(OH)D levels	Medical Outcomes Study 12-item short-form health survey	Lower Serum 25(OH)D levels associated with lower physical activity and poorer mental health QOL.
Basaran et al. (2007)[31]	259	Older Turkish women (aged 37–80 years) with osteoporosis recruited from an outpatient osteoporosis clinic in southeastern Turkey	Cross-sectional <i>Exposure:</i> 25(OH)D levels	QOL Questionnaire of the European Foundation for Osteoporosis	Excluded participants with a history of comorbidities such as cancer, chronic respiratory disease, uncontrolled diabetes mellitus, and fractures within 6 months of the study. Mental function scores were significantly lower in women with deficient 25(OH)D levels (<12 ng/mL) and insufficient 25(OH)D levels (12–20 ng/mL) compared with women with 25(OH)D levels above theirs.
Witham et al. (2010)[33]	105	Patients with systolic heart failure aged 70 years with 25(OH)D levels <50 nmol/L (20 ng/mL)	Randomized Controlled Trial <i>Treatment:</i> Oral dose of 100,000 IU D ₂ at baseline and 10 weeks <i>Placebo:</i> Placebo capsules	Minnesota Living With Heart Failure questionnaire, measured at baseline, 10 weeks, & 20 weeks	Excluded participants with osteomalacia, moderate to severe cognitive impairment, metastatic malignancy, or who were already taking vitamin D supplements. Vitamin D supplementation did not improve QOL in older patients with heart failure and vitamin D insufficiency after 20 weeks.