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Original research article

Food sources of vitamin D and their association with 25-hydroxyvitamin D status in Dutch older adults

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ABSTRACT

Various populations are at increased risk of developing a low vitamin D status, in particular older adults. Whereas sun exposure is considered the main source of vitamin D, especially during summer, dietary contributions should not be underestimated. This study aims to identify food sources of vitamin D that associate most strongly with serum vitamin D concentration. Data of 595 Dutch adults, aged ≥65 years, were analysed. Vitamin D intake was assessed with a food frequency questionnaire and 25-hydroxyvitamin D (25(OH)D) was determined in serum. Associations of total vitamin D intake and vitamin D intake from specific food groups with serum 25(OH)D status were examined by *P*-for trend analyses over tertiles of vitamin D intake, prevalence ratios (PRs), and spline regression. The prevalence of vitamin D deficiency was high, with 36% of the participants having a 25(OH)D status <50 nmol/L. Participants with adequate 25(OH)D concentrations were more likely to be men and more likely to be younger than participants with vitamin D deficiency. Total median vitamin D intake was 4.3 μg/day, of which 4.0 μg/day was provided by foods. Butter and margarine were the leading contributors to total vitamin D intake with 1.8 μg/day, followed by the intake of fish and shellfish with 0.56 μg/day. Participants with higher intakes of butter and margarine were 21% more likely to have a sufficient 25(OH)D status after adjustment for covariates (T1 vs. T3: PR 1.0 vs. 1.21 (95%CI: 1.03–1.42), *P*-for trend 0.02). None of the other food groups showed a significant association with the probability of having a sufficient 25(OH)D status. This study shows that vitamin D intake was positively associated with total serum 25(OH)D concentration, with butter and margarine being the most important contributors to total vitamin D intake.

1. Introduction

Various populations are at increased risk of developing a low vitamin D status, in particular older adults [1]. Recent studies show adverse associations between 25-hydroxyvitamin D (25(OH)D) deficiency and a broad range of health outcomes, e.g. cardiovascular and autoimmune function, neuropsychiatric health, diabetes and muscle function [2]. While more studies are needed to investigate the causality of these vitamin D-health associations, the effect on bone homeostasis is considered established [3]. Based on these classical effects of vitamin D on bone health, current dietary guidelines emphasize the need to prevent low serum 25(OH)D concentrations. Although vitamin D is primarily synthesized after sun exposure, particularly during summer months [4], dietary vitamin D intake can significantly contribute to higher serum 25(OH)D concentrations [5–8]. As such, the Institute of Medicine (IOM) and the Health Council of the Netherlands recommend a vitamin D intake between 10 and 20 μg/day to

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maintain serum 25(OH)D levels above a target value of 50 nmol/L [9,10]. Vitamin D can be obtained as ergocalciferol (vitamin D2) and cholecalciferol (vitamin D3). Limited amounts of ergocalciferol are obtained via UV-irradiated mushrooms, milk, and butter [11,12]. Cholecalciferol is mainly obtained from fatty fish (e.g. salmon, mackerel, herring) and in lesser quantities via meat, egg yolks, milk and butter [13]. Nevertheless, dietary vitamin D intakes are far below the recommended reference intake in many countries [14–16]. To prevent these observed low dietary intakes, several countries fortify specific foods with vitamin D. Fortification of milk products in the USA, and the fortification of milk and fat spreads in Canada are mandatory [17]. In addition, many countries also fortify other foods, such as cereals and fruit juices. In Europe, fortification policies differ between countries, where fat spreads and some cereals are the most commonly fortified products; milk fortification is not customary, with the exception of Finland, Norway and Sweden [18]. Currently, in the Netherlands, vitamin D food fortification is not common practice, with the exception of margarines. Vitamin D intake data from the Dutch National Food Consumption Survey (DNFCS) published in 2013 show mean vitamin D intakes of 4.1 μg/day in a population ≥70 years [19]. This average is far below the current dietary recommendation for the older adults and while specific supplementation advice is in order, only 22% of the older adults reports to use a vitamin D supplement [19]. Therefore, the importance of an adequate dietary intake should not be underestimated, especially in case of modest vitamin D inadequacy. For that reason, the aims of this study were I) to investigate which food source contributes most to total vitamin D intake, and II) to examine which food source contributes most to higher serum 25(OH)D status and adequacy in older Dutch adults.

2. Materials & methods

2.1. Study population

Cross-sectional analyses were conducted using baseline data of the B-PROOF study, which is a multi-center, placebo-controlled, double-blind, randomized trial performed by three study centers in the Netherlands (Wageningen University, Erasmus MC and VUmc). The primary aim of this study was to investigate the effect of supplementation with folic acid and vitamin B-12 to prevent osteoporotic fractures in mildly hyperhomocysteinemic adults, aged 65 years or older. Participants were recruited between August 2008 and March 2011. Main exclusion criteria were: a low or high plasma homocysteine status (<12 μmol/L or >50 μmol/L), the use of vitamin-B supplements or injections in the past 4 months, being diagnosed with cancer in the past 5 years, renal dysfunction or being bed bound. Dietary intake was only measured in the Wageningen cohort of which reliable data on vitamin D intake and 25(OH)D status were available for 595 participants. More specific information on the research protocol and study population have been described elsewhere [20]. The study protocol was approved by the Medical Ethics Committees of Wageningen UR and VUmc and the medical ethics committee of Erasmus MC confirmed local feasibility. All participants gave their written informed consent. The study was registered at ClinicalTrials.gov as NCT00696514 since June 9, 2008.

2.2. Dietary assessment

To estimate dietary vitamin D intake, an extensive Food Frequency Questionnaire (FFQ) was used of which the methods are previously described [21]. FFQ food items were categorized as total vitamin D intake, and the vitamin D intake from meat, fish and shellfish, eggs, butter and margarine, total dairy, and dairy subgroups i.e. milk, yogurt, cheese. In addition, the FFQ included questions on vitamin D supplement use, and the type, dose and frequency of the supplement.

2.3. Biochemical analyses

Blood was drawn in the morning and participants were requested to remain fasted or only take a light breakfast (according provided instructions). Serum 25(OH)D concentrations were analyzed by tandem mass spectrometry (ID-XLC–MS/MS) at the VU University Medical Centre [22]. Inter-assay coefficient of variation was 9 and 6% at a serum 25(OH)D level of 25 and 62 nmol/L, respectively.

2.4. Covariates

Weight was measured with a calibrated analogue scale to the nearest 0.5 kg. Height was measured to the nearest 0.1 cm, using a stadiometer. Body Mass Index (BMI) was reported as kg/m^2. Furthermore, each participant filled out a questionnaire to report data on education level (primary, secondary, higher), smoking (non, current, former), alcohol intake (light, moderate, excessive) [23], and physical activity (min/day) [24]. Date of blood collection was used to define a covariate for season (summer: June-November and winter: December-May).

2.5. Data analyses

General characteristics and dietary intake of the population are presented as mean (SD), median (IQR 25–75th percentile) or *n* (%) by subgroups. Subgroups were created based on serum 25(OH)D status (inadequate <50 nmol/L *versus* adequate ≥50 nmol/L) and age (<70 *versus* ≥70 years). Potential differences between subgroups were tested by ANOVA or Kruskal-Wallis test in case of continuous variables or the Chi-square test in case of categorical variables. ANCOVA analyses were used to calculate adjusted means (95% CI) per tertile of vitamin D intake from the total diet and specific food categories. *P*-for trend analysis was performed to analyze the association between vitamin D intake and serum 25(OH)D status across these tertiles. Additionally, Prevalence Ratios (PR) for serum 25(OH)D levels ≥50 nmol/L were determined by Cox proportional hazards regression with robust error variance and tertile 1 as a reference group. The hazard ratio obtained from this analysis is presented as a PR because a constant risk period was assigned to all study subjects [25]. All models were adjusted for appropriate covariates. The PRs were further investigated by restricted cubic spline regression, with knots set at the 1st, 5th and 9th decile of intake. Analyses were executed using SAS, version 9.2 statistical software (SAS Institute Inc., Cary, NC, USA) and a p-value of ≤0.05 (two-sided) was determined to be statistically significant.

3. Results

Table 1 presents the participant characteristics of the study population. The mean age of the total study population was 72 ± 5 years and 58% were men. Mean (SD) BMI was 26.9 ± 3.6 kg/m^2, serum 25(OH)D was 61 ± 26 nmol/L, and 40% of the participants were included during winter/spring. Participants with an adequate serum 25(OH)D concentration (64%) were more likely to be men (62% *versus* 52%) and more likely to be younger (71 ± 5 *versus* 73 ± 6 years), compared to participants with an inadequate serum 25(OH)D status (<50 nmol/L). Participants included in the higher age category (≥70 years) had significantly lower serum 25(OH)D concentrations (59 ± 25 *versus* 64 ± 27 nmol/L) compared to those in the younger age category (<70 years).

Table 1
Participant characteristics (n = 595).

	Total	25(OH)D <50 nmol/L	≥50 nmol/L	Age <70 years	≥70 years
N	595	212	383	225	370
Sex, n men (%)	346 (58)	110 (52)	236 (62)*	132 (59)	214 (58)
Age, years	72 ± 5	73 ± 6	71 ± 5*	67 ± 2	75 ± 4*
BMI, kg/m^2	26.9 ± 3.6	26.9 ± 3.9	26.9 ± 3.4	26.9 ± 3.7	26.9 ± 3.6
Education, n (%)					
Primary	251 (42)	99 (47)	152 (40)	94 (42)	157 (42)
Secondary	144 (24)	52 (25)	92 (24)	56 (25)	88 (24)
Higher	200 (34)	61 (29)	139 (36)	75 (33)	125 (34)
Smoking, n (%)					
Non-smoker	184 (31)	61 (29)	123 (32)	76 (34)	108 (29)
Smoker	62 (10)	27 (13)	35 (9)	27 (12)	35 (10)
Former Smoker	349 (59)	124 (58)	225 (59)	122 (54)	227 (61)
Alcohol intake, n (%)					
Light	379 (64)	156 (74)	223 (58)*	135 (60)	244 (66)
Moderate	198 (33)	48 (23)	150 (39)	80 (36)	118 (32)
Excessive	18 (3)	8 (4)	10 (3)	10 (4)	8 (2)
Physical activity, kcal/day	128 (84–193)	123 (83–193)	131 (85–193)	127 (81–194)	129 (85–191)
Serum 25(OH)D, nmol/L	61 ± 26	35 ± 11	75 ± 20*	64 ± 27	59 ± 25*
Winter/Spring, n (%)	235 (40)	114 (54)	121 (32)	74 (33)	161 (44)

BMI, Body Mass Index; 25(OH)D, 25-hydroxyvitamin D. Values represent mean ± SD, or medians (25–75th percentile).
* Significant difference between groups P ≤ 0.05.

Table 2 describes the dietary intake of the total study population stratified by serum 25(OH)D status and age. The study population had a mean fat intake of 36 ± 6 En%, protein intake of 15 ± 2, carbohydrate intake of 44 ± 7, and fiber intake of 24 ± 7 (data not shown in tables). Total median (IQR) vitamin D intake was 4.3 (3.2–5.8) μg/day, of which 4.0 (3.0–5.4) μg/day from foods. When the different food sources of vitamin D were examined, butter and margarine were the main contributors to total dietary vitamin D intake, with a median of 1.8 (0.9–2.9) μg/day (comprising 45% of dietary vitamin D intake). Fish and shellfish intake was the second most contributing dietary vitamin D source, with a median intake of 0.56 (0.22–1.04) μg/day, followed by meat intake, with a median intake of 0.40 (0.27–0.52) μg/day. Furthermore, participants with adequate serum 25(OH)D concentrations (≥50 nmol/L) had significantly higher vitamin D intakes compared to participants with inadequate serum 25(OH)D concentrations (<50 nmol/L), with a median vitamin D intake of 4.7 (3.4–6.3) versus 3.8 (3.0–5.2) μg/day. No significant differences were observed between age categories in total vitamin D intake or supplement use.

Tables 3 and 4 show the associations of serum 25(OH)D concentrations by tertiles of total vitamin D intake or intake from specific food sources. A significant association was observed between total vitamin D intake and serum 25(OH)D status, with a 10 nmol/L difference in serum 25(OH)D concentration between the lowest (<3.55 μg/day) and highest (≥5.32 μg/day) tertile of vitamin D intake (Table 3). In line with the data indicating butter and margarine as the main contributors to vitamin D intake, these data show that there is also a significant association between butter and margarine and serum 25(OH)D status. Participants with higher butter and margarine intakes (T1 vs. T3: PR 1.0 vs. 1.21 (95% CI: 1.03–1.42), *P*-for trend 0.02) have a 21% higher probability of having an adequate serum 25(OH)D status after adjustment for covariates, compared to participants with lower butter and

Table 2
Total vitamin D intake and vitamin D intake from specific food sources in a population of older Dutch adults (n = 595).

	Total	25(OH)D <50 nmol/L	≥50 nmol/L	Age <70 years	≥70 years
N	595	212	383	225	370
Energy intake, kcal/day	2005 ± 475	1933 ± 425	2044 ± 496*	2016 ± 452	1998 ± 488
Total vitamin D intake, μg/day	4.3 (3.2–5.8)	3.8 (3.0–5.2)	4.7 (3.4–6.3)*	4.3 (3.0–5.9)	4.4 (3.3–5.8)
Vitamin D supplements, μg/day	0 (0–0)	0 (0–0)	0 (0–0)*	0 (0–0)	0 (0–0)
Vitamin D from food sources					
Total foods, μg/day	4.0 (3.0–5.4)	3.7 (2.8–4.8)	4.3 (3.0–5.7)*	3.9 (2.8–5.5)	4.1 (3.1–5.3)
Meat, μg/day	0.40 (0.27–0.52)	0.38 (0.25–0.49)	0.42 (0.28–0.53)*	0.43 (0.29–0.54)	0.39 (0.26–0.51)*
Fish and shellfish, μg/day	0.56 (0.22–1.04)	0.52 (0.16–0.97)	0.58 (0.28–1.06)	0.58 (0.26–1.11)	0.56 (0.19–1.01)
Eggs, μg/day	0.25 (0.13–0.25)	0.25 (0.13–0.25)	0.25 (0.13–0.38)*	0.25 (0.13–0.25)	0.25 (0.13–0.38)
Dairy, μg/day	0.29 (0.20–0.41)	0.29 (0.18–0.41)	0.29 (0.20–0.41)	0.31 (0.20–0.41)	0.27 (0.18–0.41)
Milk, μg/day	0.04 (0.01–0.09)	0.04 (0.01–0.08)	0.04 (0.02–0.09)	0.04 (0.02–0.08)	0.04 (0.01–0.09)
Yogurt, μg/day	0.02 (0.00–0.05)	0.01 (0.00–0.05)	0.02 (0.00–0.05)	0.02 (0.00–0.05)	0.02 (0.00–0.05)
Cheese, μg/day	0.14 (0.09–0.24)	0.14 (0.08–0.21)	0.15 (0.09–0.24)	0.16 (0.10–0.25)	0.14 (0.08–0.22)*
Butter and margarine, μg/day	1.8 (0.9–2.9)	1.6 (0.7–2.6)	1.9 (1.0–3.1)*	1.7 (0.8–2.9)	1.8 (0.9–2.8)

Values represent mean ± SD, or medians (25–75th percentile).
* Significant difference between groups P ≤ 0.05.

Table 3
The association between vitamin D intake from different food sources and serum 25-hydroxyvitamin D status in older Dutch adults.

	Tertile 1	Tertile 2	Tertile 3	P for trend
Total vitamin D intake, μg/day	<3.55	3.55–5.31	≥5.32	
Serum 25(OH)D, nmol/L	57 (48 ; 65)	61 (53 ; 69)	67 (59 ; 76)	0.0004
Meat				
Total intake, g/day	44 ± 23	88 ± 16	122 ± 26	
Vitamin D intake, μg/day	<0.32	0.32–0.47	≥0.48	
Serum 25(OH)D, nmol/L	60 (52 ; 69)	61 (53 ; 69)	62 (54 ; 71)	0.73
Fish and shellfish				
Total intake, g/day	5 ± 6	14 ± 5	33 ± 24	
Vitamin D intake, μg/day	< 0.34	0.34–0.83	≥0.84	
Serum 25(OH)D, nmol/L	59 (50 ; 67)	63 (54 ; 71)	63 (54 ; 71)	0.17
Eggs				
Total intake, g/day	3 ± 2	11 ± 3	33 ± 16	
Vitamin D intake, μg/day	<0.13	0.13–0.24	≥0.25	
Serum 25(OH)D, nmol/L	61 (52 ; 69)	61 (53 ; 69)	61 (52 ; 70)	0.66
Dairy				
Total intake, g/day	251 ± 147	342 ± 151	402 ± 176	
Vitamin D intake, μg/day	<0.23	0.23–0.36	≥0.36	
Serum 25(OH)D, nmol/L	61 (53 ; 70)	63 (55 ; 71)	59 (51 ; 68)	0.32
Milk				
Total intake, g/day	65 ± 100	146 ± 90	294 ± 123	
Vitamin D intake, μg/day	<0.02	0.02–0.05	≥0.06	
Serum 25(OH)D, nmol/L	62 (53 ; 70)	61 (52 ; 69)	62 (53 ; 70)	0.89
Yogurt				
Total intake, g/day	66 ± 75	77 ± 71	160 ± 87	
Vitamin D intake, μg/day	0	0.01–0.03	≥0.04	
Serum 25(OH), nmol/L	58 (50 ; 66)	64 (56 ; 73)	64 (56 ; 73)	0.02
Cheese				
Total intake, g/day	16 ± 10	31 ± 10	62 ± 26	
Vitamin D intake, μg/day	<0.11	0.11–0.19	≥0.20	
Serum 25(OH)D, nmol/L	60 (62 ; 69)	62 (53 ; 70)	62 (54 ; 70)	0.84
Butter and margarine				
Total intake, g/day	13 ± 11	27 ± 16	47 ± 15	
Vitamin D intake, μg/day	<1.16	1.16–2.50	≥2.51	
Serum 25(OH)D, nmol/L	58 (50 ; 66)	59 (51 ; 68)	66 (57 ; 74)	0.01

25(OH)D, 25-hydroxyvitamin D. Values represent adjusted means (95% CIs) calculated by ANCOVA, adjusted for age, sex, BMI, smoking, alcohol intake, education, physical activity level, season, energy intake and vitamin D intake from other food categories. Values for total food group intakes represent mean ± SD.

margarine intakes (Table 4). Associations between total vitamin D intake from foods and vitamin D intake from butter and margarine (modelled continuously) with 25(OH)D adequacy (<50 vs. ≥50 nmol/L) are visualized in Fig. 1. None of the other vitamin D-food sources were significantly associated with 25(OH)D status.

4. Discussion

Our analyses showed that mainly butter and margarine contributed to the total vitamin D intake in this Dutch community-dwelling older population. Fish and shellfish intake was the second most important contributor to the total vitamin D intake, although comprising less than half the amount of vitamin D obtained from butter and margarine. Both total vitamin D intake as well as vitamin D intake from butter and margarine was positively associated with higher serum 25(OH)D concentrations after full adjustment for potential covariates.

Several methodological considerations should be addressed before further discussing these findings. Although the FFQ used in this study was not validated to estimate vitamin D intake, the method to compose the FFQ was validated [26,27]. As our estimated vitamin D intakes are in agreement with data obtained by two 24-h recalls of the Dutch Food Consumption Survey 2013, we assume an accurate estimate of total vitamin D intake [18]. A strength of our study includes the opportunity to not only analyze intake data, but also to link these data to serum 25(OH)D concentrations, while accounting for a broad set of potential covariates.

This study shows a high prevalence of inadequate vitamin D intake (median intake: 4.3 μg/day) in older Dutch adults. Of the total vitamin D intake reported in this study, 4.0 μg/day originated from the diet. This daily intake is intermediate in comparison to the intake of European countries, with intakes ranging between 2 and 15 μg/day [28]. The NHANES cohort showed total vitamin D intakes of 10.7 μg/day and 10.0 μg/day in American men and women aged >71y, respectively [29]. When vitamin D from supplements was excluded, mean vitamin D intakes were still higher compared to our population, that is 4.5 μg/day in women and 5.6 μg/day in men. Additionally, a Canadian cross-sectional study showed total vitamin D intakes of 8.2 μg/day and 13.6 μg/day in men and women, respectively [30]. Also in this study, higher vitamin D intakes predominantly related to higher supplemental vitamin D intakes. Specifically, supplements accounted for 56% of the total vitamin D intake, with 45% of women and 17% of men

Table 4
Prevalence ratios (95% CIs) for vitamin D adequacy (25(OH)D ≥50 nmol/L) by tertiles of vitamin D food sources.

Food sources of vitamin D	25-hydroxyvitamin D ≥50 nmol/L (n = 383)		
	Model 1	Model 2	Model 3
Total vitamin D intake, μg/day			
<3.55	1 (ref)	1 (ref)	1 (ref)
3.55–5.31	1.14 (0.96–1.34)	1.13 (0.97–1.32)	1.13 (0.97–1.32)
≥5.32	1.35 (1.16–1.57)	1.31 (1.13–1.52)	1.31 (1.13–1.52)
P for trend	<0.0001	0.0002	0.0004
Vitamin D intake from meat, μg/day			
<0.32	1 (ref)	1 (ref)	1 (ref)
0.32–0.47	0.98 (0.84–1.15)	1.01 (0.87–1.18)	0.98 (0.83–1.14)
≥0.48	1.13 (0.98–1.31)	1.14 (0.99–1.32)	1.09 (0.94–1.27)
P for trend	0.08	0.06	0.23
Vitamin D intake from fish and shellfish, μg/day			
<0.34	1 (ref)	1 (ref)	1 (ref)
0.34–0.83	1.06 (0.92–1.24)	1.02 (0.88–1.18)	1.03 (0.89–1.20)
≥0.84	1.10 (0.95–1.28)	1.05 (0.91–1.22)	1.06 (0.92–1.23)
P for trend	0.20	0.50	0.42
Vitamin D intake from eggs, μg/day			
<0.13	1 (ref)	1 (ref)	1 (ref)
0.13–0.24	1.14 (0.96–1.36)	1.09 (0.92–1.29)	1.08 (0.91–1.27)
≥0.25	1.17 (0.96–1.41)	1.11 (0.92–1.35)	1.11 (0.92–1.34)
P for trend	0.15	0.31	0.31
Vitamin D intake from dairy,μg/day			
<0.23	1 (ref)	1 (ref)	1 (ref)
0.23–0.36	1.01 (0.88–1.17)	1.00 (0.87–1.15)	1.00 (0.86–1.16)
≥0.36	1.00 (0.87–1.16)	0.99 (0.85–1.14)	0.96 (0.82–1.13)
P for trend	0.98	0.95	0.88
Vitamin D intake from milk, μg/day			
<0.02	1 (ref)	1 (ref)	1 (ref)
0.02–0.05	1.00 (0.87–1.16)	1.03 (0.89–1.18)	1.01 (0.88–1.17)
≥0.06	1.02 (0.88–1.18)	1.04 (0.91–1.19)	1.02 (0.88–1.17)
P for trend	0.79	0.58	0.83
Vitamin D intake from yogurt, μg/day			
0	1 (ref)	1 (ref)	1 (ref)
0.01–0.03	1.11 (0.96–1.29)	1.13 (0.98–1.30)	1.13 (0.98–1.30)
≥0.04	1.12 (0.96–1.29)	1.12 (0.97–1.29)	1.14 (0.98–1.31)
P for trend	0.19	0.17	0.12
Vitamin D intake from cheese, μg/day			
<0.11	1 (ref)	1 (ref)	1 (ref)
0.11–0.19	1.02 (0.88–1.18)	1.01 (0.87–1.17)	1.01 (0.87–1.17)
≥0.20	1.05 (0.91–1.22)	1.01 (0.88–1.16)	1.01 (0.87–1.17)
P for trend	0.46	0.93	0.93
Vitamin D intake from butter and margarine, μg/day			
<1.16	1 (ref)	1 (ref)	1 (ref)
1.16–2.50	1.09 (0.93–1.27)	1.09 (0.93–1.27)	1.08 (0.93–1.26)
≥2.51	1.20 (1.03–1.39)	1.22 (1.05–1.42)	1.21 (1.03–1.42)
P for trend	0.02	0.007	0.02

Model 1: incl. covariates for age and sex.
Model 2: incl. covariates of model 1 plus BMI, smoking alcohol intake, education, physical activity level, and season.
Model 3: incl. covariates of model 1 and 2 plus energy intake and vitamin D intake from other food categories.

using a supplement. In our study population, only 12% of the population used a vitamin D supplement. Moreover, higher vitamin D intakes in the US and Canada may also be explained by higher intakes of fortified products. In the US and Canada, dairy products, especially fortified milk, are considered the main food source of vitamin D intake, followed by meat and fish [30–32].

Despite relatively low vitamin D intakes in our population total vitamin D intake was significantly associated with vitamin D status. Our data also indicated that butters or margarines, are the most important sources to increase serum 25(OH)D status. Participants in the highest tertile of butter and margarine intake, representing an intake of 47 g/day (equalling 4 sandwiches with fat spread), had a 21% higher probability of having a sufficient vitamin D status. Although fish intake was the second major contributor to dietary vitamin D intake, higher fish intake was not significantly associated with higher serum 25(OH)D levels. A recent meta-analysis published by Lehman et al. investigated the effect of fish intake on serum 25(OH)D concentrations [33]. The authors showed that the consumption of ±300 g fish/wk over a period of at least 4 weeks, was associated with a significant increase in serum 25(OH) D concentrations. The non-significant association observed in this study may relate to the relatively low intake of fish in this study group (median 13 (25th–75th percentile: 7–21) g fish/week).

In the presence of adequate cutaneous vitamin D synthesis, adequate vitamin D supplement intake, and consumption of fortified foods, the importance of vitamin D intake from foods is likely to be diminished. However, according to our data, the use of supplements and fortified products is limited among older Dutch adults. As such, the total vitamin D intake lies far below the Dutch dietary reference value, currently set at an Adequate Intake (AI) of 10 μg/day for adults <70 years, and Recommended Dietary Allowance (RDA) of 20 μg/day for adults ≥70 years (based on the assumption of insufficient sunlight exposure) [9]. In our population, only 4 participants consumed at least 10 μg vitamin D day. Since 2007, the Dutch commodities act allows the addition of vitamin D to food products other than margarine (to 4.5 μg/100 kcal of product). However, food fortification is currently hardly practiced. A recent report by the National Institute for Public Health and the Environment (RIVM) shows that the fortification strategies in the Netherlands could be optimized without exceeding the tolerable upper intake level in the general Dutch population [34]. The scenario analysis indicated that the Dietary Reference Intake (DRI) could be met by >80% of the older Dutch adults when 5 μg of vitamin D would be added per 100 g of milk or yogurt, and 25 μg would be added per 100 g of margarines. Thus, food fortification in combination with the promotion of vitamin D supplement use may substantially improve the 25(OH)D status in older Dutch adults. However, as shown by our data, regular intake of foods high in vitamin D could also support an increase in vitamin D status across the general population, particularly in case of modest 25(OH)D insufficiency. Also the observed low fish/shellfish intake shows room for improving the dietary vitamin D intake. Nevertheless, for the older adults with more severe 25(OH)D deficiency, the habitual diet will not suffice in the total amount of vitamin D needed to meet the recommendations. Therefore, policies should focus on health messages regarding food fortification and vitamin D supplementation specifically targeted to this age group.

Conflicts of interest

The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results. EM Brouwer-Brolsma and LCPGM de Groot have filed a patent on the effect of vitamin D on cognitive executive function. P Lips and NM van Schoor received an unconditional grant of Merck and Co for the assessment of vitamin D in Longitudinal Aging Study Amsterdam (LASA). The other authors have no conflicts of interest to declare.

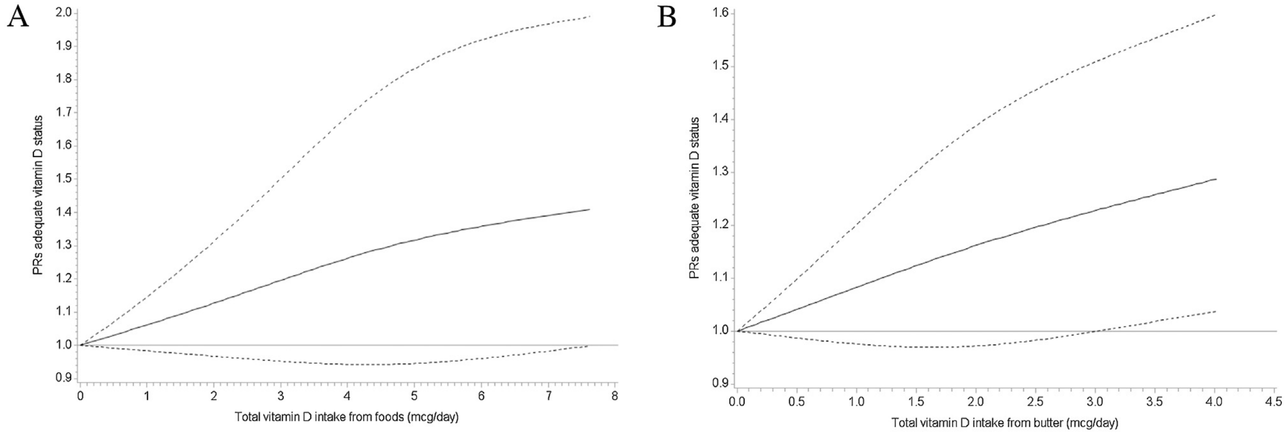

Fig. 1. Associations between vitamin D-intake and serum 25-hydroxyvitamin D concentrations $\geq$50 nmol/L (i.e. defined as adequate vitamin D status). Graphs represent Prevalence Ratios incl. 95% CIs. Models incl. covariates for age, sex, BMI, smoking, alcohol intake, education, physical activity level, season, energy intake and vitamin D intake from other food categories. A: *P* for non-linearity 0.37. B: *P* for non-linearity 0.59.

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