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ORIGINAL CONTRIBUTION

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Development of a model for optimal food fortification: vitamin D among adults in Finland

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Abstract *Background* Average vitamin D intake is low in Finland. Even though almost all retail milk and margarine are fortified with vitamin D, the vitamin D intake is inadequate for a significant proportion of the population. Consequently, expanded food fortification with vitamin D would be motivated. However, there is a risk of unacceptably high intakes due to the rather narrow range of the adequate and safe intake. Therefore, a safe and efficient food fortification practice should be found for vitamin D. *Aim of the study* To develop a model for optimal food fortification and apply it to vitamin D. *Method* The FINDIET 2002 Study (48-h recall and data on supplement use (n = 2007), and 3 + 3 days' food records, n = 247) was used as the test data. The proportion of the population whose vitamin D intake is between the recommended intake (RI) and the upper tolerable intake level (UL) was plotted against the fortification level per energy for selected foods. The fortification level that maximized the proportion of the population falling between RI and UL was considered the optimal fortification level. *Results* If only milk, butter milk, yoghurt and margarine were fortified, it would be impossible to find a fortification level by which the intake of the whole population would lie within the RI-UL range. However, if all potentially fortifiable foods were fortified with vitamin D at level 1.2–1.5 μg/100 kcal, the intake of the whole adult population would be between the currently recommended intake of 7.5 μg/d and the current tolerable upper intake level of 50 μg/day (model 1). If the RI was set to 40 μg/day and UL to 250 μg/day, the optimal fortification level would be 9.2 μg/100 kcal in the scenario where all potentially fortifiable foods were fortified (model 2). Also in this model the whole population would fall between the RI-UL range. *Conclusions* Our model of adding a specific level of vitamin D/100 kcal to all potentially fortifiable foods (1.2–1.5 μg/100 kcal in model 1 and 9.2 μg/100 kcal in model 2) seems to be an efficient and safe food fortification practise.

Key words vitamin D – fortification – adults

Introduction

Adequate vitamin D intake is essential for the normal development and maintenance of the bone [1]. In addition, in randomized controlled studies, vitamin D supplementation has been claimed to reduce the risk of falling [2]. Furthermore, high vitamin D intake has been associated with a lower risk of colorectal and prostate cancer [3, 4]. However, the evidence for a protective effect of vitamin D against cancer has been evaluated to be insufficient [5]. On the other hand, the safety range (upper tolerable intake level divided by recommended intake) for vitamin D is only 6–7 and thus rather narrow. Therefore, adverse effects from food fortification with vitamin D are possible. There are reports of vitamin D intoxication due to excessive fortification of milk [6–8] and table sugar [9]. These intoxications occur at serum 25-hydroxyvitamin D concentrations above 500 nmol/l [10], whereas a serum 25-hydroxyvitamin D concentration of 75 nmol/l is regarded as adequate [11].

In Finland, the average vitamin D intake is low, and since there is low UVB exposure, the synthesis of vitamin D in the skin is also low [12]. In 2003, fortification of margarines (10 μg/100 g), milk and butter milk, yoghurt, and products substituting milk (e.g. soy milk, 0.5 μg/100 ml) was permitted. Since then, practically all retail milk and butter milk (except organic products) and margarines have been fortified with vitamin D.

Previously, models for food fortification have been proposed by Flynn and co-workers [13] and Rasmussen and co-workers [14]. Both models give the safe upper limits for food fortification per energy unit (e.g. μg/100 kcal). Intake from natural sources constitutes the basis for calculating the level of fortification in the model presented by Flynn and co-workers, while the model of Rasmussen and co-workers also takes into account the nutrient intake from dietary supplements. However, both of these models give fixed values based on equations that use only few point estimates across the whole intake distribution. Furthermore, these models do not take into account the possibility that those who use supplements may also have a high nutrient intake from natural sources. For risk managers to decide on how big a risk is acceptable, information on the association between the risk of exceeding the UL and the fortification level is crucial. The aim of this study was to develop a model for optimal food fortification and apply it to vitamin D. We also wanted to investigate the effect of a variety of fortified foods on the efficiency and safety of fortification.

Subjects and methods

The FINDIET 2002 Study provided data for this study [12]. The FINDIET 2002 Study is a national survey that was carried out as part of the FINRISK 2002 Study which monitors cardiovascular risk factors. A random sample of 12,000 persons 25–64 years of age and stratified by sex and 10-year age groups was drawn from the population register. The participation rate was 65% (7,784 subjects).

The FINDIET 2002 Study was carried out in five areas: (1) the Helsinki metropolitan area, (2) the cities of Turku and Loimaa, and some rural communities in southwestern Finland, and in the provinces of (3) North Karelia, (4) North Savo, and (5) Oulu. Of the invited subjects, 32% were randomly selected to participate in the dietary survey. The final number of participants in the dietary survey was 2007 subjects. The participants were interviewed using the 48-h recall method. The dietary intake data covered all days of the week except Fridays. A subsample (n = 247) of the participants filled in a 3-day food record twice (the first starting the day after 48-h recall in early spring, and the second in autumn). The National Food Composition Database Fineli® (www.fineli.fi) was used to calculate the intake of vitamin D from foods.

Data on the use of dietary supplements during the preceding 6 months were collected with a questionnaire. Participants filled in the brand name of the supplement, dosage, and frequency of use. A separate dietary supplement database was used to calculate the intake of vitamin D from supplements.

Total non-fortified intake of vitamin D was calculated as the sum of the intakes from natural sources and from dietary supplements (Fig. 1). Energy underreporters were excluded (n = 735) using 1.00*BMR (basal metabolic rate) as the cut-off point [15].

The optimal fortification level was estimated by plotting the proportion of the population whose vitamin D intake is between the recommended intake (RI) and the upper tolerable intake level (UL) against the fortification level per energy (unit) for the sum of all potentially fortifiable foods (Figs. 1 and 2). We used the RI (7.5 μg/day) and UL (50 μg/day) values as determined in the Nordic Nutrition Recommendations [16]. In addition, we repeated the analyses using the recently proposed RI (40 μg/day), [15] and UL (250 μg/day) [10]. Two fortification levels were determined: the first one (no risk of exceeding UL) was the highest level where the proportion of people exceeding the UL was 0%. The other level (optimal) was the fortification level that minimized the proportion of people falling outside the RI-UL range. For each of these points, the total nutrient intake (natural sources + dietary supple-

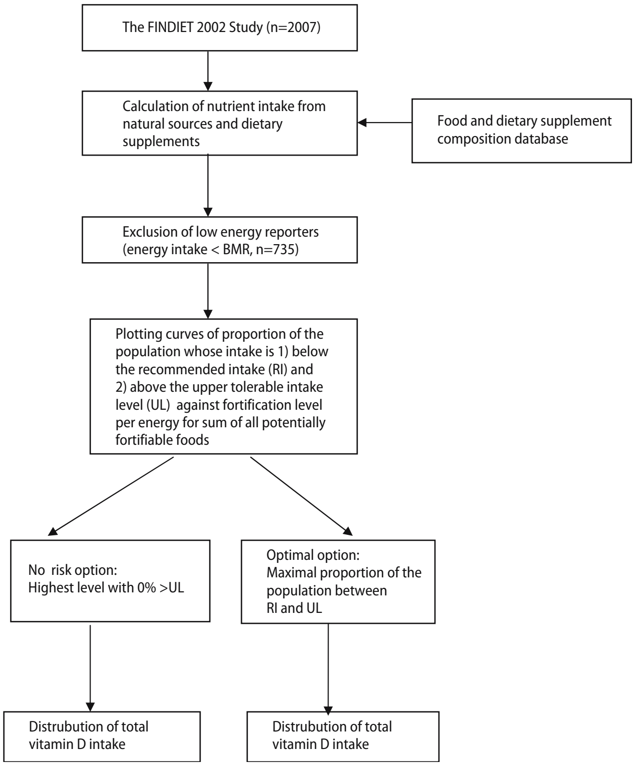

Fig. 1 Flow chart of the analysis. RI: recommended intake; UL: upper tolerable intake level; BMR: basal metabolic rate

ments + food fortification) was calculated, and the distributions were estimated using the method of Nusser and co-workers [17]. This method gives the long-term average of daily intakes (usual daily intake) by taking into account the day-to-day correlation and nuisance effects (such as day-of-week and interview sequence). It also allows for exceptions from normality through grafted polynomial transformations and recognizes the measurement error associated with one-day dietary intakes. The estimations were done using the SAS based SIDE® software.

The models were fitted with different combinations of fortified foods: (a) milk, butter milk, yoghurt, and margarine, (b) milk, butter milk, yoghurt, margarine, and fruit juice, (c) milk, butter milk, yoghurt, margarine, fruit juice, and bread, or (d) all fortifiable foods (milk, butter milk, yoghurt, margarine, fruit juice, bread, cultured milk, cheese, milk dessert, ice cream, ready-to-eat breakfast cereals, jam, sweets, soft drinks, biscuits, mineral water, salad dressing, and snacks) fortified.

Results

The characteristics of the subjects and the sources of vitamin D are presented in Table 1. In Fig. 1, the proportion of the population outside the RI-UL range is plotted against the fortification levels per energy (unit) in the four different fortification scenarios. As the fortification level increases, the proportion of those above the UL increases at a much slower rate than the proportion below RI decreases. In the scenario closest to the present situation (Fig. 2A, Table 2), it was not possible to find a fortification level where 100% of the population would be within the RI-UL range. However, when the food selection was increased, it was possible to find a fortification level where 100% of the population was between RI-UL range (Fig. 2C, D, Table 2). In the scenario where all potentially fortifiable foods are fortified with vitamin D, the proportion of the population within the RI-UL range was 100%, when the fortification level was between 0.012 μg/kcal and 0.015 μg/kcal. The vitamin D intake distributions produced by the four scenarios are presented in Fig. 3. In comparison either to a situation with no fortification or to the current situation, the intake of vitamin D would be much higher with the optimal fortification level (Fig. 3, Table 2).

When RI was set to 40 μg/day and UL to 250 μg/day, the optimal fortification level was 0.092–0.102 μg/kcal in the scenario where all potentially fortifiable foods are fortified with vitamin D (Fig. 4). In this scenario, the proportion of the population within the RI-ul range was 100%.

Discussion

With the nutrient density based method applied in this study, it is possible to find a fortification level that is both efficient in reducing the proportion of those with low nutrient intake and safe in avoiding the risk of exceeding the UL, provided that all potentially fortifiable foods are fortified.

Both the method of Rasmussen and co-workers [14] and that of Flynn and co-workers [13] resulted in approximately the same fortification levels for vitamin D as our method did (Rasmussen et al.: 1.5 μg/100 kcal, Flynn et al.: 1.8 μg/100 kcal), when we used an RI of 7.5 μg/day and an UL of 50 μg/day. In fact, the method of Rasmussen and co-workers gave exactly the same fortification level as ours when using the scenario where all potentially fortifiable foods were fortified. As a consequence, with the fortification level given by our method and by the method of Rasmussen and co-workers, the vitamin D intake of the whole population remained within the RI-UL range. However, with the fortification level obtained by the method of Flynn and co-workers, a small proportion (0.3%) of the population exceeded the UL in the scenario that included all potentially fortifiable foods. Even though the main principle of our method

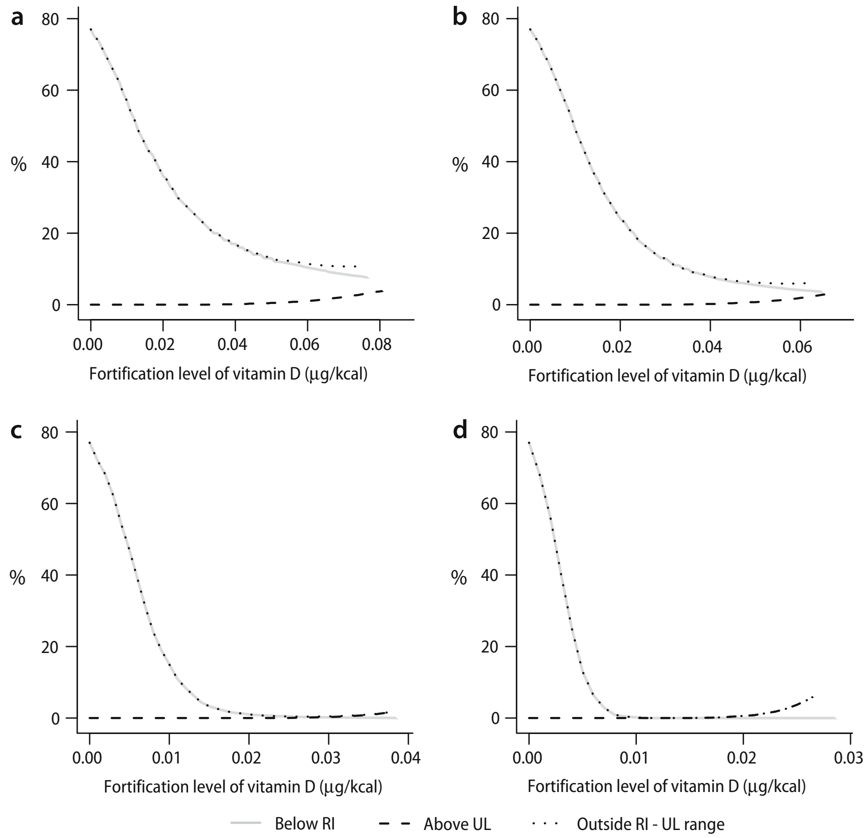

Fig. 2 Fortification with vitamin D per energy (unit) by proportion of population below RI (7.5 μg/day) and proportion of the population exceeding the UL (250 μg/day) in four fortification scenarios. (A) milk, butter milk, yoghurt, and margarine fortified; (B) milk, butter milk, yoghurt, margarine, and fruit juice fortified; (C) milk, butter milk, yoghurt, margarine, fruit juice, and bread fortified D: all potentially fortifiable foods fortified

Table 1 Age, years of education, and sources of vitamin D (μg/day (% of total intake)) by vitamin D intake quartiles in the FINDIET 2002 Study (energy undereporters excluded)

	Men[a], $n = 614$				Women[b], $n = 658$			
	I	II	III	IV	I	II	III	IV
Age, years	43.8 (11.7)	44.1 (11.2)	43.5 (11.4)	48.5 (11.1)	41 (11.1)	44.3 (11.6)	44.3 (11.9)	46.6 (11.2)
Years of education	12.5 (3.71)	12.6 (3.49)	12.9 (3.82)	12.1 (3.83)	13.7 (3.71)	12.8 (3.6)	13.2 (3.61)	13.1 (3.75)
Fish foods and products	0.08 (4.32)	0.31 (8.02)	1.51 (21.63)	8.94 (53.54)	0.05 (3.3)	0.46 (13.13)	1.37 (20.63)	5.31 (36.85)
Spreads	0.29 (15.17)	0.45 (11.62)	0.56 (7.97)	2.31 (13.85)	0.22 (14.2)	1.03 (29.70)	1.29 (19.47)	1.12 (7.80)
Milk and sour milk	0.2 (10.64)	0.23 (5.86)	0.28 (4.02)	0.27 (1.61)	0.15 (9.60)	0.21 (6.01)	0.18 (2.69)	0.19 (1.31)
Egg foods	0.07 (3.56)	0.31 (8.01)	0.30 (4.30)	0.42 (2.50)	0.05 (3.20)	0.19 (5.44)	0.11 (1.64)	0.19 (1.32)
Poultry foods	0.11 (5.53)	0.16 (4.17)	0.12 (1.78)	0.12 (0.73)	0.11 (6.97)	0.14 (4.09)	0.11 (1.72)	0.11 (0.79)
Cereal products	0.30 (15.51)	1.4 (36.04)	2.23 (31.9)	0.56 (3.33)	0.32 (20.90)	0.38 (10.94)	0.45 (6.73)	0.41 (2.81)
Other foods	0.86 (44.83)	0.95 (24.4)	0.97 (13.81)	1.34 (8.00)	0.61 (39.96)	0.67 (19.25)	0.74 (11.23)	0.89 (6.15)
Foods in total	1.90 (99.55)	3.81 (98.13)	5.98 (85.41)	13.95 (83.55)	1.49 (98.12)	3.07 (88.56)	4.25 (64.1)	8.22 (57.02)
Dietary supplements	0.01 (0.45)	0.07 (1.87)	1.02 (14.59)	2.75 (16.45)	0.03 (1.88)	0.40 (11.44)	2.38 (35.90)	6.2 (42.98)
Total vitamin D intake	1.91 (100)	3.88 (100)	7.00 (100)	16.7 (100)	1.52 (100)	3.47 (100)	6.63 (100)	14.42 (100)

[a] Quartiles of daily vitamin D intake in men: I: < 2.97 μg. II: 2.97 −4.92 μg. III: 4.43–9.92 μg; IV: > 9.92 μg
[b] Quartiles of vitamin D intake in women: I: < 2.33 μg. II: 2.33–4.97 μg. III: 4.98–8.90 μg; IV: > 8.90 μg

is similar to the previously presented methods, i.e. fortification is made per energy unit, [13, 14], it has the unique feature that the fortification level is not pre-fixed but can be related to the acceptable risks of low and excessive intakes. This method gives useful information for a risk manager whose task is to balance between these two risks and to decide how big a risk is acceptable.

There are few previous studies examining the impact of food fortification on the vitamin D intake at the population level. In a comparison made between populations with varying fortification practices, it was observed that in countries where milk is fortified, vitamin D intake is higher than in other countries [18]. However, since the consumption of milk is usually skewed, fortification of milk alone is far from

Table 2 Effect of different fortification scenarios on vitamin D intake

Fortification scenario*		µg/100 kcal	Mean (µg/day)	Median (µg/day)	<2.5 µg/day (%)	<7.5 µg/day (%)	>50 µg/day (%)
No fortification			5.6	4.6	16.5	76.5	0
Current fortification			8.3	7.3	3.5	52.2	0
A	No risk	3.2	12.6	11.5	1.0	22.0	0
	Optimal	0.72	22.4	20.4	0.6	7.6	3.2
B	No risk	3.2	14.7	13.7	0.3	11.0	0
	Optimal	5.5	21.5	20.0	0.2	4.7	1.2
C	No risk	2.4	20.1	19.5	0	0.5	0
	Optimal	2.6	21.4	20.6	0	0.3	0.06
D	No risk/opt.	1.5	23.0	22.4	0	0	0

[a] Current fortification: almost all milk (0.5 µg/100 ml), butter milk (0.5 µg/100 ml) and household margarines (010 µg/100 g); some yoghurts (0.5 µg/100 ml) and one mineral water (0.1 µg/100 ml) are fortified
A: Milk, butter milk, yoghurt, and margarine are fortified
B: Milk, butter milk, yoghurt, margarine, and fruit juice are fortified
C: Milk, butter milk, yoghurt, margarine, fruit juice, and bread are fortified
D: All fortifiable foods (milk, butter milk, yoghurt, margarine, fruit juice, bread, cultured milk, cheese, milk dessert, ice cream, ready-to-eat breakfast cereals, jam, sweets, soft drinks, biscuits, mineral water, salad dressing, and snacks) fortified

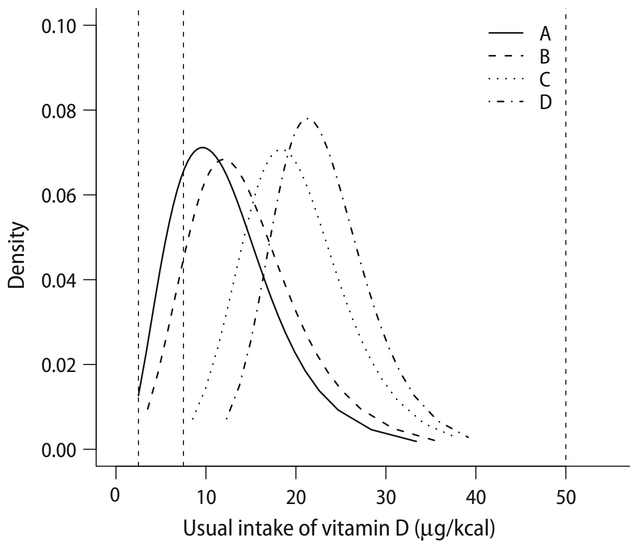

Fig. 3 Distributions of vitamin D intake in different fortification scenarios. See Fig. 2. for notes

optimal. Rasmussen and co-workers claimed that combining milk fortification with margarine fortification would be optimal in Denmark [19]. This is in line with our study in showing that food fortification with vitamin D is more efficient when a wide variety of foods are fortified with a low concentration, rather than only few with high concentration. When only few foods are fortified with a high concentration, the risk of overdose is pronounced among those who use large quantities of these particular foods. When several foods are fortified with lower concentrations, the risk of overdose is smaller since nobody can consume high quantities of all foods. This is in line with the recently published article [20] which showed that despite the current vitamin D fortification practice (0.5 µg/100 g to milk and 10 µg/100 g to margarines), significant proportion (29%) of young men had vitamin D deficiency in winter.

Fortification of mineral water and soft drinks is somewhat problematic, since they are probably consumed more in summer or in warm and sunny areas than in other occasions. Therefore, this study may have underestimated the use of soft drinks and mineral water, because the FINDIET 2002 Study was conducted in early spring and in autumn. In this respect, dietary supplements are safer because their intake can be interrupted during the summer. It is more difficult to suspend the fortification of a certain food for a short period of time.

When the optimal fortification level is searched for, it should be borne in mind that the recommended intake is a relative concept. It is not necessary that the intake of all individuals of the population is above the recommended intake level. However, while it is not necessary for the whole population to lie within the RI-UL range, it is essential that the whole population exceeds the lower intake level (LI). On the other hand, the mean intake in the population equaling the recommended intake does not necessarily indicate sufficient intake. The intake is sufficient, if everybody reaches the LI and as many as possible reach the RI. In contrast, the concept of a tolerable upper intake level is not relative, but definitive. Consequently, the aim should be that nobody in the population exceeds the UL and as many as possible reach the recommended intake. In our analysis, estimated average requirement (EAR) might have been a more useful reference value than the recommended intake, but EAR is not available in the Nordic Nutrition Recommendations for vitamin D [16]. We have not only used the current Nordic RI and UL of 7.5 and 50 µg to develop a model for optimal food fortification, but

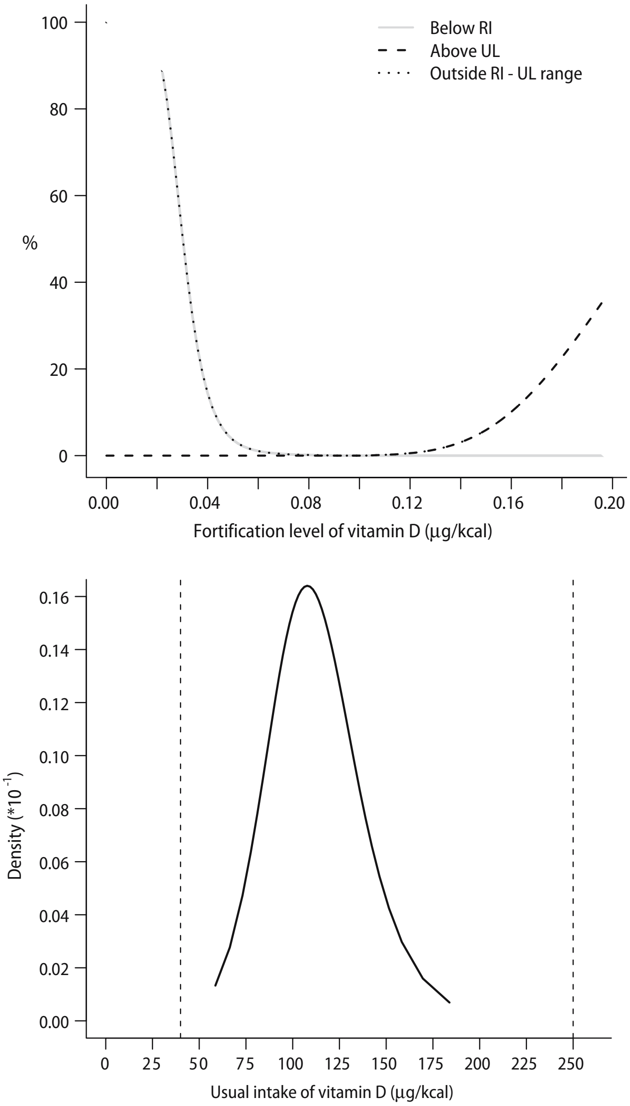

Fig. 4 Fortification with vitamin D per energy (unit) by proportion of population below RI (40 μg/day) and proportion of the population exceeding the UL (250 μg/day) in a scenario where all potentially fortifiable foods are fortified (upper part) and the distribution of vitamin D intake at fortification level 0.092 μg/kcal (lower part)

also used an RI of 40 μg/day and an UL of 250 μg/day. This was necessary since there is increasing evidence that the current RI and UL for vitamin D are far too low [21].

In our intake calculations, it is assumed that the proportion of fortification is 100% in each food group. In reality, this is not usually the case, since only some of the brands are fortified. However, from the risk management point of view, it is not reasonable to assume that some brands only are issued the licence to fortify, i.e. food fortification within a food group should be considered safe either in all brands or in none.

Our study sample consisted of adults aged 25–64 years. However, Rasmussen and co-workers pointed out that different nutrients are critical for different age groups. Therefore, this method presented here should also be tested in other age groups, especially in children. There is no reason to doubt this method would not be applicable to other age groups as well. However, the optimal fortification level should be separately estimated for children.

When using the nutrient density based method presented here it should be kept in mind that most dietary surveys include marked energy underreporting. Therefore, if underreporting is not taken into account, the method gives too high fortification levels and there is a high risk that a considerable proportion of the population will exceed the UL. However, even though underreporters were excluded, there is probably still a high proportion of underreporters in the data because the cut-off value used is quite low (1.00*BMR). Therefore, a certain safety margin should be considered when the highest food fortification concentration is defined.

We conclude that adding vitamin D to foods would be a safe and effective way to reduce the number of individuals with low vitamin D intake. It is safer and more efficient to fortify several different foods with a low concentration of vitamin D than to fortify only few foods with a high concentration.

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