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Total number of authors:
13

Published in:
Scandinavian Journal of Public Health

Link to article, DOI:
10.1177/1403494819896878

Publication date:
2021

Document Version
Peer reviewed version

Scandinavian Journal of Public Health, 1–12

LITERATURE REVIEW

Vitamin D status and current policies to achieve adequate vitamin D intake in the Nordic countries

SUVI T. ITKONEN[1], RIKKE ANDERSEN[2], ANNE K. BJÖRK[3], ÅSA BRUGÅRD KONDE[4], HANNA ENEROTH[4], MAIJALIISA ERKKOLA[1], KRISTIN HOLVIK[5], AHMED A. MADAR[6], HAAKON E. MEYER[5,6], INGE TETENS[7], JÓHANNA E. TORFADÓTTIR[8,9], BIRNA THÓRISDÓTTIR[9,10] & CHRISTEL J.E. LAMBERG-ALLARDT[1]

[1]Department of Food and Nutrition, University of Helsinki, Helsinki, Finland, [2]Division for Diet, Disease Prevention and Toxicology, National Food Institute, Technical University of Denmark, Kongens Lyngby, Denmark, [3]Department of Medical Sciences, Endocrinology and Mineral Metabolism, Uppsala University, Uppsala, Sweden, [4]Science Division, National Food Agency, Uppsala, Sweden, [5]Department of Chronic Diseases and Ageing, Norwegian Institute of Public Health, Oslo, Norway, [6]Department of Community Medicine and Global Health, University of Oslo, Oslo, Norway, [7]Vitality – Centre for Good Older Lives, Department of Nutrition, Exercise, and Sports, University of Copenhagen, Copenhagen, Denmark, [8]Centre of Public Health Sciences, Faculty of Medicine, University of Iceland, Reykjavik, Iceland, [9]Icelandic Cancer Society, Reykjavik, Iceland, and [10]Faculty of Sociology, Anthropology and Folkloristics, School of Social Sciences, University of Iceland, Reykjavik, Iceland

Abstract

Aims: Nordic countries share fairly similar food culture and geographical location as well as common nutrition recommendations. The aim of this paper was to review the latest data on vitamin D status and intake and to describe the national supplementation and food fortification policies to achieve adequate vitamin D intake in the Nordic countries. *Methods:* The data are based on results derived from a literature search presented in a workshop held in Helsinki in November 2018 and completed by recent studies. *Results:* Vitamin D policies and the implementation of the recommendations differ among the Nordic countries. Vitamin D fortification policies can be mandatory or voluntary and widespread, moderate or non-existent. Vitamin D supplementation recommendations differ, ranging from all age groups being advised to take supplements to only infants. In the general adult population of the Nordic countries, vitamin D status and intake are better than in the risk groups that are not consuming vitamin D supplements or foods containing vitamin D. Non-Western immigrant populations in all Nordic countries share the problem of vitamin D insufficiency and deficiency. ***Conclusions:*** **Despite the common nutrition recommendations, there are differences between the Nordic countries in the implementation of the recommendations and policies to achieve adequate vitamin D intake and status. There is a need for wider Nordic collaboration studies as well as strategies to improve vitamin D status, especially in risk groups.**

Keywords: *Vitamin D, Nordic, policy, nutrition recommendations, implementation, vitamin D status, 25-hydroxyvitamin D, vitamin D fortification, vitamin D intake, nutrition*

Background

The importance of vitamin D in bone health is well recognized [1]. There is also suggestive evidence of other health benefits of vitamin D related to pregnancy outcomes, some types of cancer, cardiovascular diseases, risk of falls and mortality; however, the evidence from observational studies has not been consistently

Correspondence: Suvi T Itkonen, Department of Food and Nutrition, University of Helsinki, FIN-00014, Finland.
E-mail: suvi.itkonen@helsinki.fi

Date received 4 July 2019; reviewed 30 October 2019; accepted 27 November 2019

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DOI: 10.1177/1403494819896878
journals.sagepub.com/home/sjp
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Table I. Recommended vitamin D intakes in the Nordic Nutrition Recommendations 2012.

Recommended intake (RI)	µg/d
Infants, children and adolescents	10
18–60 y	10[a]
61–74 y	10[a]
⩾ 75 y	20
Pregnant and lactating women	10
Average requirement (AR)	7.5
Lower intake level (LI)	2.5
Upper intake level (UL)[b]	100

[a]If little or no sunshine exposure, 20 µg/d is recommended.
[b]European Food Safety Authority: infants aged 0–6 months 25 µg/d, infants aged 6–12 months 35 µg/d, children aged 1–10 years 50 µg/d, adolescents aged 11–17 years and adults 100 µg/d [5,6].

confirmed by intervention studies [1]. Vitamin D can be obtained from cutaneous synthesis, diet and supplements [1]. Ultraviolet B (UVB) exposure is needed for the cutaneous synthesis of vitamin D; 7-dehydrocholesterol is photo-converted to previtamin D_3, which is further converted to vitamin D_3 [2]. Ingested and cutaneous D_3 is transported in the circulation to the liver where it is converted to 25-hydroxyvitamin D (25(OH) D). It is further converted in the kidney to the active form of vitamin D, 1,25-dihydroxyvitamin D (1,25$(OH)_2$D), that has various biological functions [1]. 1,25$(OH)_2$D has a short half-life, and 25(OH)D is the major circulating form of vitamin D; thus, 25(OH) D is considered a biomarker of vitamin D status [1].

At higher latitudes, including the Nordic countries (55–72°N), sunlight is not qualitatively or quantitatively sufficient for UVB-induced vitamin D_3 synthesis in the skin to take place during certain periods of the year, leading to the so-called vitamin D winter [3]. Based on the calculations by O'Neill et al. [3], in, for example, Tromsø, Norway (69°N), the vitamin D winter lasts eight months, and in Copenhagen (55°N) six months. In addition, there are only a few natural sources rich in vitamin D: (fatty) fish, egg yolk and some wild mushrooms [1]. Thus, not surprisingly, widespread vitamin D insufficiency (serum 25(OH) D (or S-25(OH)D) <50 nmol/l) in the Nordic countries has been common [1,4].

The Nordic countries share fairly similar food culture and geographical location and, since 1968, also common nutritional recommendations [4]. In the most recent Nordic Nutrition Recommendations (NNR) 2012, the recommended daily vitamin D intake was increased from 7.5 µg to 10 µg, and to 20 µg in those 75 years and older [4]. To achieve sufficient intake levels of vitamin D, some of the Nordic countries have initiated national policies of mandatory or recommendation-based voluntary fortification of certain foods with vitamin D. Further, vitamin D supplementation has been taken into account in the nutrition recommendations to ensure adequate vitamin D intake also in specific risk groups. The aim of this paper was to review the latest data on vitamin D status and intake as well as to describe the national supplementation and food fortification policies to achieve adequate vitamin D intake in the Nordic countries. This article is a part of the project 'Update on the vitamin D status and its determinants in the Nordic countries' financed by the Nordic Council of Ministers. The data are based on results derived from the literature search presented in a workshop held in Helsinki in November 2018 (https://www.helsinki.fi/en/conferences/workshop-on-vitamin-d-status-in-the-nordic-countries), complemented by the latest studies in May 2019.

Nordic Nutrition Recommendations for vitamin D

The NNR for vitamin D refer to a set of dietary reference values, including average requirement (AR), recommended intake (RI), upper intake level (UL) and lower intake level (LI) (Table I) [4].

The NNR for vitamin D are based on a systematic literature review providing scientific evidence on the potential health effects and on the dietary intake of vitamin D required to maintain S-25(OH)D above sufficient concentrations (defined as ⩾50 nmol/l) all year round at the Nordic latitudes [1]. The systematic literature review concluded that a dietary RI of 15 µg/d of vitamin D was needed to maintain the target of ⩾50 nmol/l assumed by minimal sun exposure. However, the current recommendations consider a contribution of sun-induced vitamin D synthesis from outdoor activities during the summer season (late spring to early autumn), which is compatible with normal, everyday life and is also in line with recommendations on physical activity. The exception is subjects with limited sun-induced vitamin D synthesis due to older age, skin protection related to cultural traditions, limited access to outdoor activities or skin pigmentation. The recommendations are aimed at the population level, not for individuals or for patient care.

In the NNR, the AR was assessed from randomized controlled intervention studies conducted in the Nordic countries with data obtained during wintertime on vitamin D status (S-25(OH)D) in relation to dietary intake of vitamin D. The AR for vitamin D intake sufficient to maintain a mean serum concentration in half the subjects of about 50 nmol/l is 7.5 µg/d for age groups 2 years and above, including pregnant and lactating women [4]. The RI for vitamin D was assessed as the lower 95% confidence interval in the fitted line on the relationship between vitamin D status and vitamin D intake. The RI covers

total vitamin D intake, that is, both dietary and supplemental intake. The RI is 10 μg/d for infants aged 2 weeks to adults aged 74 years and 20 μg/d for older subjects (⩾75 years). For individuals with little or no sunshine exposure, 20 μg/d is recommended. LI is defined as a cut-off intake value below which a long-term intake could lead to clinical deficiency symptoms in most individuals [4]. UL is defined as the maximum level of long-term (months or years) daily nutrient intake that is unlikely to pose a risk of adverse health effects in humans [4]. In the NNR, ULs were not determined but ULs established by the European Food Safety Authority (EFSA) were applied [5]. EFSA ULs for infants were updated in 2018 and they apply to the Nordic countries [6].

Denmark, Finland, Norway and Sweden have implemented the NNR 2012 vitamin D recommendations as such. In Iceland, the RIs of vitamin D are slightly higher than those of other Nordic countries: 10 μg/d for infants and children up to 9 years of age, 15 μg/d for children from 10 years and adults up to 70 years, and 20 μg/d for those older than 70 years [7].

Recommendations for vitamin D supplementation

Vitamin D supplementation recommendations in the Nordic countries are described in detail in Table II. In the NNR, vitamin D supplementation is recommended for all infants from the first weeks to 2 years [4]. Supplements are not recommended as such for any other groups in the NNR. There are some differences in the supplementation recommendations between the Nordic countries to achieve the recommended vitamin D intake (Table II).

In all Nordic countries, vitamin D supplementation is recommended to infants [7–11]. In Norway and Finland, the vitamin D doses for infants ⩽1 year of age are adjusted on the amount of infant formula [8,9]. In Finland and Iceland all children under 18 years are advised to take vitamin D supplements [7,9]. In Sweden and Denmark, the NNR infant supplementation recommendation is implemented directly [10,11].

In Finland, Denmark and Iceland, all pregnant and breastfeeding women are advised to take vitamin D supplements [7,9,10]. In Sweden and Norway, the supplementation recommendations for these risk groups are determined by sun exposure and dietary habits [11,12].

As an exception to other Nordic countries, in Iceland vitamin D supplements are recommended for all adults especially in the winter [7]. In other Nordic countries, the supplementation recommendations for adults should be applied depending on the consumption of vitamin D–rich foods, sunlight exposure and clothing habits. Regarding the older population, vitamin D supplementation is recommended for all subjects over 70–75 years of age in all Nordic countries, except in Norway, where supplementation is not recommended during summer in the event of adequate sun exposure and high dietary vitamin D intake [7,9–12]. Dark-skinned individuals are recommended to take vitamin D supplements in Denmark and Norway [10,12] but no group-specific recommendations have been given in Sweden, Finland or Iceland.

Vitamin D fortification policies

Vitamin D fortification policies in the Nordic countries are summarized in Table III. Vitamin D fortification policies differ between Nordic countries (Table III). Finland is an example of a successful vitamin D fortification policy that has contributed markedly to the country's improved vitamin D status [13]. Recommendation-based fortification of fluid milk products (except for organic ones) and fat spreads (not butter) started in 2002 and the fortification levels were doubled in 2010 [14]. Even though the fortification policy is voluntary, almost all domestic manufacturers follow the current recommendations. However, some products such as yoghurts are not fortified widely with vitamin D despite the recommendation. Of the organic products, only one type of milk is allowed to be fortified with vitamin D due to special legislation [15]. The change in legislation was made because organic milks were becoming more popular at daycares and schools. In Sweden, the low-fat milks and solid margarines are mandatorily fortified with vitamin D, and from 2018 the fortification policy included a wider range of products. All milk with fat $<$ 3% and sour milk products, lactose-free products, vegetable-based alternatives and fluid margarines are recommended to be fortified [16].

In Norway, butter, margarine and some types of low-fat milk are voluntarily fortified with vitamin D, but with lower amounts than in Finland and Sweden [12]. However, based on a recent report by the Norwegian National Nutrition Council [12], the vitamin D fortification policy in Norway is targeted for change. The report recommends that to reach high-risk groups vitamin D fortification should cover a wider range of products with moderate vitamin D concentrations rather than a few products with high concentrations. Specifically, fortification should be extended to all fluid milk products and vegetable-based alternatives and maintained in butter and margarine. Fortification of juice, bread and cooking oils should also be considered [12]. In Denmark, vitamin D fortification of foodstuffs needs to be approved by the Danish Veterinary and Food Administration before the food can be placed on the Danish market [17]. The approval is based on an individual risk

Table II. Vitamin D supplementation recommendations in the Nordic countries [4,7–12].

Country	Adults/general population	Infants and children	Older people	Pregnant and lactating women	Dark-skinned individuals
Nordic Nutrition Recommendations	-	0–2 y 10 μg/d	-	-	-
Denmark	Individuals not spending time outdoors or avoiding sunlight 10 μg/d	0–2 y 10 μg/d	> 70 y & nursing home residents 20 μg/d + 800–1000 mg/d Ca	10 μg/d	Dark-skinned individuals/ persons with concealed clothing 10 μg/d
Finland	Individuals not consuming vitamin D–rich foods during wintertime 10 μg/d	All under 18 y: 0–1 y 10 μg/d or if infant formula is consumed, depending on the amount of infant formula[a], 1 y 10 μg/d, ⩾2 y 7.5 μg/d	⩾75 y 20 μg/d or less if vitamin D sources on diet	Pregnant women 10 μg/d, breastfeeding women 10 μg/d	Not specified
Iceland	Total intake from diet and supplements 15 μg/d	Total intake from diet and supplements: 0–9 y 10 μg/d, 10–17 y 15 μg/d	Total intake from diet and supplements: over 70 y 20 μg/d	Total intake from diet and supplements: pregnant and breastfeeding women 15 μg/d	Follow the age-specific recommendations
Norway	10 μg/d if both sun exposure and consumption of vitamin D–containing foods is low[b]	Infants 0–12 months 5 μg/d through vitamin D drops or cod liver oil from 4 weeks of age, gradual increase to 10 μg/d from 6 months of age[c], 10 μg/d for older infants and children if sun exposure and intake from food is low	20 μg/d if both sun exposure and consumption of vitamin D–containing foods is low, otherwise 10 μg/d[c]	10 μg/d if both sun exposure and consumption of vitamin D–containing foods is low[b]	10 μg/d if consumption of vitamin D–containing foods is low[b]
Sweden	Depending on diet and sun exposure 10–20 μg/d if necessary[d]	Children under 2 y 10 μg/d, children over 2 y depending on diet and sun exposure 10–20 μg/d if necessary[d]	>75 y 20 μg/d	Pregnant women who do not consume fortified products or fish or are using concealed clothing should seek advice from midwife	Not specified

[a]Fully breastfed infant or infant receiving less than 500 ml/d infant formulas (including also vitamin D–fortified cereal porridges) 10 μg/d, infant receiving 500–800 ml/d infant formulas 6 μg/d, infant receiving more than 800 ml/d infant formulas 2 μg/d.

[b]Supplementation recommended during wintertime for those with normal outdoor activity, otherwise throughout the year.

[c]For older people, no supplementation during summertime if intake from food is high and outdoor activity is normal.

[d]Adults and children who do not eat fish and vitamin D–fortified products should take a 10 μg daily supplement. Supplementation may be interrupted from May to August, but can also be taken year-round. The same recommendation is given for those wearing clothing that prevents sun exposure. If above-mentioned vitamin D sources are not consumed and if also sun exposure is prevented with covering clothing, a 20 μg daily dose of vitamin D is recommended.

Table III. Authority-driven vitamin D food fortification policies in the Nordic countries [12,14–18].

Country	Type of fortification	Products that are systematically fortified with vitamin D	Added amount of vitamin D
Denmark	Voluntary[a]	-	-
Finland	Voluntary, recommendation-based	Fluid milk products[b] (milk, yoghurt, sour milk)	1 μg/100 g
		Margarine and fat spreads (not butter)	20 μg/100 g
Iceland	Voluntary[a]	-	-
Norway	Voluntary, recommendation-based	Low-fat milk (also lactose-free)	0.4 μg/100 g
		Margarine and butter	10 μg/100 g
Sweden	Mandatory	Milk < 3% fat, also lactose-free and vegetable-based alternatives	0.95–1.10 μg/100 g
		Sour milk < 3% fat, also lactose-free and vegetable-based alternatives	0.75–1.10 μg/100 g
		Margarine, fat spreads and fluid margarine	19.5–21.0 μg/100 g

[a]See details in text.
[b]Of organic milk products, it is mandatory to add 1 μg/100 g vitamin D to homogenized fat-free milk (not allowed on other organic milk products).

assessment carried out on a case-by-case basis by the National Food Institute. However, the Danish Veterinary and Food Administration has generally accepted addition of vitamin D to certain products [17]. Only a few products in categories such as fat spreads, sports drinks and lactose-free milk products are fortified with vitamin D. In Iceland, some imported foods are fortified with vitamin D, for example, some vegetable oils and cereals [18]. Domestic production is not subjected to mandatory fortification and is not universal, but most fat spreads and some types of fluid milk (albeit with a minor market share) are fortified with vitamin D.

According to EU legislation, infant formulas should contain a minimum of 2 μg and a maximum of 2.5 μg vitamin D per 100 kcal based on Commission Delegated Regulation (EU) 2019/828 [19]. A minimum of 2 μg and a maximum of 3 μg vitamin D per 100 kcal is allowed to be added to follow-on formulas in accordance with the delegated act (EU) 2016/127 [20]. Vitamin D 1–3 μg per 100 kcal can be added to cereal-based products with a high protein (traditionally milk-based) content. Other cereal-based foods for infants may contain a maximum of 3 μg vitamin D per 100 kcal according to Commission Directive 2006/125/EC [21]. In all other baby foods (dishes, purees, etc.), the addition of vitamin D is not allowed. Directive 2006/125/EC is being revised at the moment. All Nordic countries follow this EU legislation concerning infant nutrition.

Vitamin D intake and sources of vitamin D

Online Supplemental Table I shows vitamin D intakes in the Nordic countries. The latest population-based data on vitamin D intakes cover mainly only adult populations in the Nordic countries. Data for adults in the general population were derived from national surveys mostly carried out between 2010 and 2013, that is, before implementation of the latest NNR, except for Finland, where the latest national dietary survey was carried out in 2017.

Adults and older adults

Mean vitamin D intake in Norway and Finland reached the recommended 10 μg/d when supplement use was taken into account [22,23]. In Finland, vitamin D intakes from habitual diet were 9–10 μg/d among women and 13 μg/d among men in 2017 [23]. A total of 40% of men and 57% of women used vitamin D supplements [23]. In Norway, mean vitamin D intake, excluding supplements, was 5 μg/d in women and 7 μg/d in men, and 40% reported use of vitamin D–containing supplements in 2010–2011 [12]. In Sweden, the mean vitamin D intake from habitual diet was 6 μg/d among women and 8 μg/d among men in the latest dietary survey among adults in 2010–2011 [24]. A total of 21% of the participants used some vitamin or mineral supplements: 50% of the supplements were either omega 3 products or multivitamin products and 5% vitamin D supplements with or without calcium [24]. In Denmark, during 2011–2013, mean vitamin D intake from habitual diet was 4 μg/d among women and 5 μg/d among men [25]. Among women and men, respectively, 11% and 6% used vitamin D supplements, 54% and 43% used multivitamin or multimineral supplements and 18% and 5% used calcium+vitamin D supplements [26]. In Iceland, during 2010–2011, men almost reached 10 μg/d on average as a total from habitual diet and supplements, but the intake among women was lower, 7 μg/d, and 35% reported

cod liver oil use and 8% cod liver oil capsule use, respectively [27]. Among the older age groups in the Nordic countries, vitamin D intakes were slightly higher (Online Supplemental Table I).

The main dietary vitamin D sources among adult populations in the Nordic countries are fish and vitamin D–fortified products. In Denmark, the main sources were fish and meat products, fish covering 57% of vitamin D intake [25]. In Finland, fortified fat spreads contributed to 32–37% of vitamin D intake, milk products to 25–26% and fish products to 20–22% [23]. In Norway, fish contributed 40%, fat spreads 30% and eggs 17% [22]. Fish, fat spreads and dairy products covered most vitamin D intake in Sweden, the proportions being 32%, 14% and 12%, respectively [24]. In Iceland, two-thirds of vitamin D originated from cod liver oil and fish [27].

Children, immigrants and pregnant women

Among children, the intakes were generally low, except in Finland, where compliance with supplementation recommendations is high (Online Supplemental Table I). Data on 3–6-year-old Finnish preschool children in 2015–2016 showed that mean vitamin D intakes from habitual diet were 9 μg/d among girls and 10 μg/d among boys, and 81–84% used vitamin D supplements [28]. Among the younger population in Sweden, 11% of 11–21-year-olds used dietary supplements; 24% of those were vitamin D supplements and 25% multivitamin supplements [29]. In Denmark, 2% of 4–10-year-olds and 5% of 11–17-year-olds used vitamin D supplements, the corresponding proportions being 61% and 44% for multivitamins and 3% and 5% for calcium+vitamin D supplements [26]. Among 6-year-old Icelandic children in 2011–2012, 26% took cod liver oil daily and 27% often [30].

Concerning immigrants living in the Nordic countries, smaller studies suggest that habitual vitamin D intakes from diet among immigrants originating from Asia and Africa are low [31,32]. However, a recent dietary survey among infants and toddlers of mothers with Somali or Iraqi background in Norway showed that median vitamin D intakes were now 12–14 μg/d at 12 months of age and 7–9 μg/d at 2 years of age due to widespread supplementation [33]. A low prevalence of vitamin D supplement use among adult Asian and African immigrants has been observed [34,35]. In contrast, at the baseline of two small intervention studies, among a small population of Pakistani women in Denmark, 61% used vitamin D supplements and 30% multivitamin supplements in 2015 [32] and among a population of Somali women in Finland, 88% used vitamin D supplements in 2014 [36].

Among pregnant women, when supplement use was included, vitamin D intakes in the Nordic countries usually met the recommendations of 10 μg/d [37–40].

Vitamin D status

Plasma/serum 25(OH)D concentrations of ⩾50 nmol/l are considered sufficient, while concentrations of 30–49 nmol/l indicate insufficiency and <30 nmol/l deficiency [2,4]. 25(OH)D concentrations are affected by vitamin D intake from habitual diet or supplements, exposure to sunlight (season, latitude, travelling to sunny places, use of sunscreen), skin pigmentation, age, genetic background and amount of fat mass [1,4]. Large differences between laboratories in the results of 25(OH)D measurements have been reported, and there is an international goal to use standardized protocols for analyses to ensure comparability between datasets [41]. The 25(OH)D concentrations in some larger Danish, Finnish, Norwegian and Icelandic cohorts have been standardized in the Vitamin D Standardization Program [42,43]. However, no standardized data are available from Sweden. Furthermore, some of the data that has been standardized is not very recent. Figure 1 shows standardized S-25(OH)D concentrations in different nationally or regionally representative or non-representative population groups [42,43]. Standardized data show that among adults in Finland, Denmark and Norway S-25(OH)D concentrations were on average sufficient; the proportion having S-25(OH)D <50 nmol/l was 7–24%. In an Icelandic study among older adults, the mean concentrations were slightly lower (and the proportion having <50 nmol/l higher) than in the above-mentioned studies. In the Danish studies regarding 4–17-year-old children, the mean concentrations were >50 nmol/l (17–37% <50 nmol/l) but a teenage population in Tromsø, Northern Norway had a mean concentration of 38 nmol/l, with 76% having status <50 nmol/l. The poorest vitamin D status among the standardized data was found in Pakistani-origin immigrants in Oslo, Norway, 92% of them having 25(OH)D <50 nmol/l. In a pooled data of three different immigrant groups in Finland (Russian, Kurdish and Somali), 64% had an adequate vitamin D status, the persons of Kurdish background having the lowest status.

Results of studies regarding vitamin D status, that is, S-25(OH)D concentration in the Nordic countries in different population groups (adults and older adults, children and adolescents, immigrants and other risk groups), are described in Online Supplemental Table II.

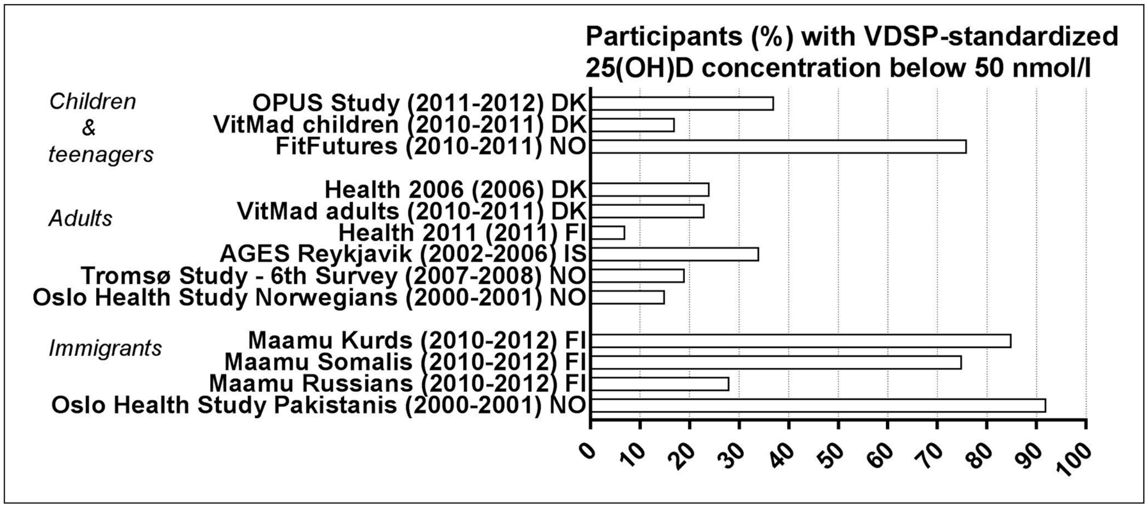

Figure 1. Proportion of population having Vitamin D Standardization Program (VDSP)-standardized serum 25-hydroxyvitamin D (25(OH)D) concentrations below 50 nmol/l in Nordic studies [35,42,43].

Adults and older adults

Based on data derived from the larger studies, mean 25(OH)D concentrations among adults in the Nordic countries were around 60–65 nmol/l, except in Iceland, where the mean concentrations were lower. Concentrations were higher among supplement users, and also seasonal variation was present. In a Danish longitudinal study, clear seasonal variation was seen; year-round median values were 43 nmol/l among men and 57 nmol/l among women, and during spring time 60% of men and 42% of women had 25(OH)D <50 nmol/l, whereas the corresponding figures for autumn were 18% and 13% [44]. The latest studies in Finland show that 25(OH)D concentrations in the general population have increased from the 2000s [13,45]. In August–December, the mean concentrations in both sexes were 65 nmol/l and 9% had 25(OH)D <50 nmol/l [13], whereas in January–April the mean concentrations among men were 63 nmol/l and among women 67 nmol/l, with 26% of men and 21% of women having 25(OH)D <50 nmol/l [45]. However, the analysis methods in these two studies are not directly comparable. In a cohort from Tromsø, Northern Norway, 36% of the participants had 25(OH)D <50 nmol/l [43], whereas data from the Oslo Health Study in 2000–2001 showed a prevalence of 15% in Norwegian-born participants (compared with 92% in Pakistani-born participants) [42]. In a Sami and Norwegian population in rural Northern Norway (68–70°N), one-fourth had S-25(OH)D <50 nmol/l [46]. In Swedish adults (aged 18–80 years), the mean 25(OH)D concentrations among women were 65 nmol/l (21% <50 nmol/l) and among men 62 nmol/l (24% <50 nmol/l) [11]. The latest representative adult population study from Iceland is from 2001 to 2003, and the mean concentration among supplement (including cod liver oil) users during wintertime was 47 nmol/l, whereas it was 29 nmol/l among those who did not use supplements [47]. However, samples collected between 2002 and 2006 among elderly Icelandic persons with a mean age of 77 years showed mean concentrations to be >50 nmol/l, but 34% had concentrations below this cut-off [43]. The proportions of elderly individuals having inadequate vitamin D status (<50 nmol/l) were lowest in Finland and Sweden, 5–17%, and highest in Norway and Denmark, over 50% [11,13,48,49]; however, only the Finnish results were standardized. The Swedish and Danish studies were not representative of the population, and in the Norwegian study there were geographical differences.

Children and adolescents

Studies regarding children and adolescents in Sweden, Denmark and Iceland show that mean 25(OH)D concentrations were >50 nmol/l and the proportion of 25(OH)D <50 nmol/l ranged from 8% to 48% [29,30,44,50,51]. However, among Swedish adolescents aged around 17 years, the mean concentration was <50 nmol/l, and 62% had S-25(OH)D <50 nmol/l [29]. Seasonal variation in S-25(OH)D concentrations was perceived in Danish children (67 nmol/l in autumn versus 44 nmol/l in spring), being stronger among children not using supplements (66 versus 36 nmol/l, respectively) [44]. Among Icelandic 6-year-old children, 55% had S-25(OH)D <50 nmol/l in winter/spring, compared with 38% in autumn and 24% in summer [30]. No seasonal

differences were observed among children following vitamin D supplementation recommendations (10 μg/d). As previously mentioned, three out of four adolescents in Northern Norway had 25(OH)D <50 nmol/l [43]. In Finland, a study among 10-year-olds showed adequate mean 25(OH)D concentrations and 16% had 25(OH)D <50 nmol/l [52]. In a study of Finnish newborn infants living in the metropolitan area, only 1% had inadequate cord blood 25(OH)D concentration [53].

Pregnant women and immigrants as risk groups

Studies show that pregnant Caucasian women have seemingly good vitamin D status, the proportion having <50 nmol/l ranging from 1% to 28% in different population groups [54–57]. However, immigrants of Asian, Middle East and African origin are at risk of vitamin D deficiency and have much lower vitamin D status than their Nordic peers without immigrant background [e.g. 31,35,55,56,58]. Swedish and Norwegian studies have demonstrated that pregnant women without Nordic background are at high risk of vitamin D deficiency and their 25(OH)D concentrations are low [55,56]. In a Swedish study, African or Asian origin was a risk factor for low vitamin D status and deficiency; up to 82% of pregnant women of African background and 69% of Asian background had inadequate vitamin D status [55]. In Norway, especially pregnant women with South Asian, Middle Eastern or Sub-Saharan African origin had a high prevalence (75–84%) of vitamin D insufficiency at the 15th gestation week [56]. In the latest data regarding Pakistani women in Denmark, one-third had insufficient vitamin D status [32]. The Finnish immigrant study revealed that immigrants of Russian origin had mean 25(OH)D status similar to the age- and region-matched Finnish population in 2010–2012, but among Somalis and Kurds, the status was much lower; 75% and 85%, respectively, had S-25(OH)D <50 nmol/l [35]. Nevertheless, a smaller study carried out in 2014 among Somali women in Finland showed slightly higher mean 25(OH)D concentrations (56 nmol/l); however, 56% of subjects had inadequate status [36]. In Norway, exclusively breastfed infants with immigrant background had poor vitamin D status, which, however, improved after provision of free vitamin D drops in the mother-and-child health centres [59]. This programme was implemented nationally in 2009. A later study showed that while the 25(OH)D concentrations had improved among immigrant infants aged 9–16 months, half of them still had S-25(OH)D <50 nmol/l [60].

Discussion

Even though Nordic countries share common nutrition recommendations for vitamin D, national policies to achieve adequate intake are quite different. Finland and Sweden have implemented both vitamin D fortification policy of foodstuffs and supplementation recommendations for subgroups [9,14]. In Denmark, there is no tradition of dietary fortification with vitamins, but dietary supplements are frequently used and generally accepted, partly compensating for the low vitamin D intake from the diet in some groups. Norway and Iceland have a long tradition of cod liver oil use as supplements and as part of a regular diet [1]. Moreover, Norway has made some efforts to improve vitamin D intake through a mild fortification policy with addition of vitamin D to butter and margarines for several decades and later also to milk [12]. Also, as an outdoor nation, Norwegians stress the effects of sunshine as a source of vitamin D [12]. Iceland has higher vitamin D intake recommendations than the other Nordic countries, taking into account reports from the Institute of Medicine and the EFSA as well as the latitude of the country, resulting in limited days of sun exposure. Thus, the daily RI for the adult Icelandic population is 15 μg/d [7]. In Iceland, supplements are recommended for everyone, especially in the winter months, to facilitate reaching the goal of 15 μg/d [7].

Mean vitamin D status among adult populations seems to be at approximately the same level in the Nordic countries in some cohorts (60–65 nmol/l), except in Iceland, where the concentrations are lower, but the data are older. Despite the adequate mean concentrations, a notable proportion of the Nordic populations have 25(OH)D <50 nmol/l, indicating vitamin D insufficiency. Especially dark-skinned individuals are at risk of vitamin D deficiency and insufficiency based on the latest Nordic data [12,35,55,56]. Average vitamin D intakes in the general population in Finland and Norway are slightly higher than those in the other Nordic countries. In Finland, this is due to a strong and widespread vitamin D fortification policy and in part due to increased supplement use [13,23], and in Norway mainly due to the prevalent use of vitamin D supplementation through cod liver oil and multivitamins [22]. However, without supplement use, vitamin D intakes in Norway are far below the RIs. As Sweden has implemented new food fortification regulations recently [16], the situation there may be changing. Moreover, vitamin D intakes in the population groups vary widely. The Finnish data show especially high intakes among supplement users, and, interestingly, adequate vitamin D intake in

these adults is on an average obtained already from the habitual diet [23]. In the NNR, supplements are recommended only for infants until the age of 2 years, but individual countries have made their own decisions about supplementation politics, which also differ widely [7,9–12]. However, the studies among children and adolescents show low vitamin D intakes and a high prevalence of vitamin D insufficiency, indicating that vitamin D obtained only from the diet is not sufficient to reach the RI or adequate serum concentrations [29,30,40,42,44,50–52]. The current vitamin D intake may not be sufficient to maintain adequate vitamin D status for growth and development.

Sun exposure is important for vitamin D status, but in the Nordic countries the sun is available for adequate vitamin D synthesis for only part of the year [3]. The amount of vitamin D_3 produced in the skin is dependent on various factors, including season, latitude, skin pigmentation, age and area of exposed skin [2]. Thus, at northern latitudes, vitamin D must be obtained from sources other than cutaneous synthesis during part of the year, stressing the role of diet and supplementary vitamin D intake. The Danish study on vitamin D status showed a noteworthy seasonal variation in insufficiency rates; for example, in spring time the prevalence among men was 60% and in autumn only 18% [44]. Also the Finnish data from two different population-based studies with sampling times in autumn 2011 and winter/spring 2012 revealed different proportions of subjects having S-25(OH)D $<$50 nmol/l: 9% versus 21–26% [13,45]. For dark-skinned individuals, some of them using concealing clothing, sun exposure during summertime was not sufficient. Therefore, there is a need for comprehensive guidelines for vitamin D supplementation in addition to the recommendations for consumption of vitamin D–rich foods.

There are limitations in the available data. Some of the studies are small and some are regional and not representative of the whole country. However, regarding vitamin D intake among adults, fairly current nationally representative data were available. When comparing vitamin D status in the Nordic countries, more emphasis should be placed on VDSP-standardized results. However, these data are not available from Sweden. Further, VDSP-standardized data do not cover all population groups from all countries. Differences in blood sampling seasons hinder the comparison.

Also, validity and comparability of dietary and supplementary intake estimates may suffer from methodological biases. Preferably, a calculation of usual intake distributions should be applied by using, for example, the National Cancer Institute method or the Statistical Program to Assess Dietary Exposure. Taking into account day-to-day intra-person variation results in a better estimate of the true distribution of nutrient intakes. This improves the estimates of the proportions of the population with intakes above or below particular reference values (e.g. UL, AR), which otherwise would be overestimated.

Conclusions

Adequate vitamin D status is important for public health. Since reaching the RIs of vitamin D is challenging due to the limited amounts available in many food items and lack of sun exposure, an effective strategy should be sought by Nordic countries sharing similar geographical location and food culture. Currently, there are differences between the countries in the implementation of the recommendations and the policies to achieve adequate vitamin D intake and status. Vitamin D fortification policies can be mandatory or voluntary and widespread, moderate or non-existent. Vitamin D supplementation recommendations also differ, ranging from all age groups being recommended to take supplements to only infants. In the general population of the Nordic countries, vitamin D status and intake are suboptimal, but seemingly better than in the risk groups that are not consuming vitamin D supplements or foods containing vitamin D. Non-Western immigrant populations of all Nordic countries seem to share the problem of vitamin D insufficiency and even deficiency. Moreover, it should be kept in mind that infants, children, older adults and individuals staying indoors always are at risk of vitamin D deficiency if active measures are not taken to ensure adequate intake. To be able to update knowledge regarding vitamin D intake and status in different population groups, there is a need for wider Nordic collaboration studies as well as for strategies to improve vitamin D status, especially in risk groups. These studies should also take into account genetic variance in vitamin D metabolism.

Contribution of authors

STI and CJELA were responsible for the design and planning of the study. RA, AKB, ÅBK, HE, ME, KH, AAM, HEM, IT, JET and BT gave an input to the planning of the study. All authors contributed to the interpretation of the data. STI drafted the manuscript. All authors revised and approved the final version of the manuscript.

Declaration of conflicting interests

The authors have no conflicts of interest to declare.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This article was written as part of the project 'Update on vitamin D status and its determinants in the Nordic countries' financed by the Nordic Council of Ministers.

ORCID iDs

Suvi T. Itkonen https://orcid.org/0000-0003-1635-8229
Kristin Holvik https://orcid.org/0000-0003-3132-2822

Supplemental material

Supplemental material for this article is available online.

References

[1] Lamberg-Allardt C, Brustad M, Meyer HE, et al. Vitamin D – a systematic literature review for the 5th edition of the Nordic Nutrition Recommendations. *Food Nutr Res* 2013;57.
[2] Institute of Medicine Food and Nutrition Board. *Dietary reference intakes for adequacy: calcium and vitamin D*. Washington (DC): The National Academies Press; 2011.
[3] O'Neill CM, Kazantzikis A, Ryan MJ, et al. Seasonal changes in vitamin D-effective UVB availability in Europe and associations with population serum 25-hydroxyvitamin D. *Nutrients* 2016;8:E533.
[4] Nordic Council of Ministers. *Nordic Nutrition Recommendations*. Copenhagen (Denmark): Norden; 2014.
[5] EFSA Panel on Dietetic Products, Nutrition and Allergies. Scientific opinion on the tolerable upper intake level of vitamin D. *EFSA J* 2012;10:2813.
[6] EFSA Panel on Dietetic Products, Nutrition and Allergies. Scientific opinion on the update of the tolerable upper intake level for vitamin D for infants. *EFSA J* 2018;16:e05365.
[7] Icelandic Directorate of Health. *Dietary recommendations for adults and children from 2 years*. Reykjavik, Iceland: Directorate of Health, 2014. (In Icelandic).
[8] Norwegian Directorate of Health. Nasjonal faglig retningslinje for spedbarnsernæring (National guideline for infant nutrition). https://helsedirektoratet.no/retningslinjer/spedbarnsernering (2016, accessed 01 July 2019).
[9] Finnish National Nutrition Council. *Finnish nutrition recommendations – health from food*. (Suomalaiset ravitsemussuositukset – Terveyttä ruoasta 2014, in Finnish). 5th revised ed. Helsinki: PunaMusta, 2018.
[10] Danish Health Authority. D-vitamin. https://www.sst.dk/da/sundhed-og-livsstil/ernaering/d-vitamin (2017, accessed 15 July 2018).
[11] Brugård Konde Å. Råd om D-vitamintillskott till riskgrupper. (Advice on vitamin D supplementation). Livsmedelverkets rapportserie nr 21 2018. (In Swedish) https://www.livsmedelsverket.se/bestall-ladda-ner-material/sok-publikationer/artiklar/2018/2018-nr-21-rad-om-d-vitamintillskott-till-riskgrupper (2018, accessed 1 May 2019).
[12] Norwegian National Nutrition Council. Nasjonalt råd for ernaering. Vitamin D i Norge: Behov for tiltak for å sikre god vitamin D-status? (Vitamin D in Norway) IS-2772. Utgitt 11/18. (In Norwegian) https://helsedirektoratet.no/publikasjoner/vitamin-d-i-norge-behov-for-tiltak-for-a-sikre-god-vitamin-d-status (2018, accessed 13 January 2019).
[13] Jääskeläinen T, Itkonen ST, Lundqvist A, et al. The positive impact of general food fortification policy on vitamin D status in a representative adult Finnish population: evidence from an 11-year follow-up based on standardized 25-hydroxyvitamin D data. *Am J Clin Nutr* 2017;105: 1512–1520.
[14] Finnish National Nutrition Council. Report of vitamin D working group. (Valtion ravitsemusneuvottelukunta. D-vitamiinityöryhmän raportti. In Finnish) https://www.ruokavirasto.fi/teemat/terveytta-edistava-ruokavalio/ravintoaineet/d-vitamiini/ (2010, accessed 15 January 2019)
[15] Finnish Ministry of Agriculture and Forestry. Regulation 754/2016 about vitamin D fortification of fat-free homogenized organic fluid milk. FINLEX. (Maa- ja metsätalousministeriön asetus rasvattoman homogenoidun maidon D-vitaminoinnista). (In Finnish) http://www.finlex.fi/fi/laki/alkup/2016/20160754 (2016, accessed 15 March 2018).
[16] Swedish National Food Authority. Livsmedelsverket. Livsmedelverkets föreskrifter (LIVSFS 2018:5) om berikning av vissa livsmedel (Food Agency's order about fortification of foodstuffs). https://www.livsmedelsverket.se/globalassets/om-oss/lagstiftning/berikn—kosttillsk—livsm-spec-gr-fsmp/livsfs-2018–5_web.pdf (2018, accessed 01 June 2018)
[17] Danish Veterinary and Food Administration. How to market fortified food in Denmark. https://www.foedevarestyrelsen.dk/english/Food/Fortified_food/Pages/default.aspx (2019, accessed 1 July 2019).
[18] Steingrimsdottir L, Thorkelsson G and Eythorsdottir E. Chapter 6 – Food, nutrition and health in Iceland. In: Andersen V, Bar E and Wirtanen G (eds) *Nutritional and health aspects of foods in Nordic countries*. London: Elsevier, 2018, Elsevier Traditional and Ethnic Food Series, pp.158–209.
[19] Commission Delegated Regulation (EU) 2019/828 of 14 March 2019 amending Delegated Regulation (EU) 2016/127 with regard to vitamin D requirements for infant formula and erucic acid requirements for infant formula and follow-on formula. https://eur-lex.europa.eu/legal-content/FI/TXT/?uri=OJ:L:2019:137:TOC (2019, accessed 01 July 2019).
[20] Commission Delegated Regulation (EU) 2016/127 of 25 September 2015 supplementing Regulation (EU) No 609/2013 of the European Parliament and of the Council as regards the specific compositional and information requirements for infant formula and follow-on formula and as regards requirements on information relating to infant and young child feeding. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32016R0127 (2016, accessed 01 July 2019).
[21] Commission Directive 2006/125/EC of 5 December 2006 on processed cereal-based foods and baby foods for infants and young children. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1561981297143&uri=CELEX:32006L0125 (2006, accessed 01 July 2019).
[22] Totland TH, Kjerpeseth Melnaes B, Lundberg-Hallén N, et al. Norkost 3. En landsomfattende kostholdsundersøkelse blant men nog kvinner i Norge i alderen 18–70 år 2010–2011 (A representative study on nutrient intakes among 18–70-year-old men and women in Norway). Helsedirektoratet. Anvord Grafisk AS: Oslo, Norway. (In Norwegian with English abstract).
[23] Valsta L, Kaartinen N, Tapanainen H, et al. (eds). Ravitsemus Suomessa – FinRavinto 2017 -tutkimus. (Nutrition in Finland – The National FinDiet 2017 Survey). Institute for Health and Welfare (THL). Report 12/2018. Helsinki; PunaMusta Oy. (In Finnish with English abstract). http://

www.julkari.fi/handle/10024/137433 (2018, accessed 15 February 2019).

[24] Amcoff E, Edberg A, Enghardt Barbieri H, et al. Riksmaten - vuxna 2010–2011. Livsmedels- och näringsintag bland vuxna i Sverige. (Food and nutrient intake among adults in Sweden). Livsmedelsverket: Uppsala, Sweden. (In Swedish with English abstract). https://www.livsmedelsverket.se/globalassets/publikationsdatabas/rapporter/2011/riksmaten_2010_20111.pdf?id=3588 (2012, accessed 01 June 2018).

[25] Pedersen AN, Christensen T, Matthlessen J, et al. Danskernes kostvaner 2011–2013 – Hovedresultater. Dietary habits in Denmark 2011–2013 – Main results. DTU Fødevareinstituttet. (In Danish with English abstract). https://www.food.dtu.dk//media/Institutter/Foedevareinstituttet/Publikationer/Pub-2015/Rapport_Danskernes-Kostvaner-2011–2013.ashx?la=da&hash=6272131AA16D3E74CA5B7B3E770BD24C62DBB8B5 (accessed 15 July 2018).

[26] Knudsen VK. Danskernes forbrug af kosttilskud. (Supplement use among Danes) E-artikel fra DTU Fødevareinstitutet, (2), 1–6. (In Danish). orbit.dtu.dk/files/. . ./Danskernes_forbrug_af_kosttilskud.pdf (2014, accessed 13 January 2019).

[27] Thorgeirsdóttir H, Valgeirsdóttir H, Gunnarsdóttir I, et al. Hvað borða Íslendingar? Könnun á mataræði Íslendinga 2010–2011. Helstu niðurstöður. Landlaeknir. https://www.landlaeknir.is/servlet/file/store93/item14901/Hva%C3%B0%20bor%C3%B0a%20%C3%8Dslendingar_april%202012.pdf (2012, accessed 15 July 2018).

[28] Skaffari E, Korkalo L, Vepsäläinen H, et al. Daycare-aged children's diet. The report. (In Finnish). Päiväkoti-ikäisten lasten ruokavalio -raportti. Helsingin yliopisto. https://dagis.fi/raportit-muut-julkaisut/ (2019, accessed 1 July 2019).

[29] Warensjö Lemming E, Moraeus L, Petrelius Sipinen J, et al. Riksmaten ungdom 2016–17. Näringsintag och näringsstatus bland ungdomar i Sverige. (Riksmaten adolescents) Livsmedelsverket Nr 23. (In Swedish with English abstract). https://www.livsmedelsverket.se/matvanor-halsa–miljo/kostrad-och-matvanor/matvanor—undersokningar/riksmaten-ungdom (2018, accessed 15 January 2019).

[30] Thorisdottir B, Gunnarsdottir I, Steingrimsdottir L, et al. Vitamin D intake and status in 6-year-old Icelandic children followed up from infancy. *Nutrients* 2016;8:75.

[31] Björk A, Andersson Å, Johansson G, et al. Evaluation of sun holiday, diet habits, origin and other factors as determinants of vitamin D status in Swedish primary health care patients: a cross-sectional study with regression analysis of ethnic Swedish and immigrant women. *BMC Fam Pract* 2013;14:129.

[32] Grønborg IM, Tetens I, Christensen T, et al. Vitamin D-fortified food improve wintertime vitamin D status in women of Danish and Pakistani origin living in Denmark: a randomized controlled trial. *Eur J Nutr*. Epub ahead of print 9 Mar 2019. doi: 10.1007/s00394–019–01941–6.

[33] Kolve CS, Grewal NK, Terragni L, et al. InBaKost 12 månader. En undersøkelse av ammepraksis og kosthold blant norsksomaliske og norsk-irakiske 12 måneder gamle barn i østlandsområdet. (InBaKost 12 months. A study on weaning practices and diet among Norwegian Somalis and Norwegian Irak 12-month-old children in eastern area). (In Norwegian). CC-BY-SA Høgskolen i Oslo og Akershus. HiOA Rapport nr 12. https://skriftserien.hioa.no/index.php/skriftserien/article/view/76/75 (2016, accessed 13 May 2019).

[34] Madar AA, Stene LC and Meyer HE. Vitamin D status among immigrant mothers from Pakistan, Turkey and Somalia and their infants attending child health clinics in Norway. *Br J Nutr* 2009;101:1052–1058.

[35] Adebayo FA, Itkonen ST, Lilja E, et al. Prevalence and determinants of vitamin D deficiency and insufficiency among three immigrant groups in Finland – evidence from a population-based study using standardized 25-hydroxyvitamin D data. *Public Health Nutr*, in press.

[36] Adebayo FA, Itkonen ST, Öhman T, et al. Vitamin D intake, serum 25-hydroxyvitamin D status and response to moderate vitamin D3 supplementation: a randomized controlled trial among in East African and Finnish women. *Br J Nutr* 2018;119:431–441.

[37] Jensen CB, Petersen SB, Granström C, et al. Sources and determinants of vitamin D intake in Danish pregnant women. *Nutrients* 2012;4:259–272.

[38] Meinilä J, Koivusalo SB, Valkama A, et al. Nutrient intake of pregnant women at high risk of gestational diabetes. *Food Nutr Res* 2015;59:26676.

[39] Gunnarsdottir I, Tryggvadottir EA, Birgisdottir BE, et al. Diet and nutrient intake of pregnant women in capital area of Iceland. *Laeknabladid* 2016;102:378–384.

[40] Gustafsson MK, Romundstad PR, Stafne SN, et al. Alterations in the vitamin D endocrine system during pregnancy: a longitudinal study of 855 healthy Norwegian women. *PLoS One* 2018;13:e0195041.

[41] Binkley N and Sempos CT, for the Vitamin D Standardization Program (VDSP). Standardizing vitamin D assays: the way forward. *J Bone Miner Res* 2014;29:1709–1714.

[42] Cashman KD, Dowling KG, Škrabáková Z, et al. Standardizing serum 25-hydroxyvitamin D data from four Nordic population samples using the Vitamin D Standardization Program protocols: shedding new light on vitamin D status in Nordic individuals. *Scand J Clin Lab Invest* 2015;75:549–561.

[43] Cashman KD, Dowling KG, Škrabáková Z, et al. Vitamin D deficiency in Europe: pandemic? *Am J Clin Nutr* 2016;103:1033–1044.

[44] Hansen L, Tjonneland A, Koster B, et al. Vitamin D status and seasonal variation among Danish children and adults: a descriptive study. *Nutrients* 2018;10:E1801.

[45] Raulio S, Erlund I, Männistö S, et al. Successful nutrition policy: improvement of vitamin D intake and status in Finnish adults over the last decade. *Eur J Public Health* 2017;27:268–273.

[46] Petrenya N, Lamberg-Allardt C, Melhus M, et al. Vitamin D status in a multi-ethnic population of northern Norway: the SAMINOR 2 Clinical Survey. *Public Health Nutr*. Epub ahead of print 15 February 2019. doi: 10.1017/S1368980018003816.

[47] Steingrimsdottir L, Gunnarsson O, Indridason OS, et al. Relationship between serum parathyroid hormone levels, vitamin D sufficiency, and calcium intake. *JAMA* 2005;294:2336–2341.

[48] Andersen R, Brot C, Jakobsen J, et al. Seasonal changes in vitamin D status among Danish adolescent girls and elderly women: the influence of sun exposure and vitamin D intake. *Eur J Clin Nutr* 2013;67:270–274.

[49] Holvik K, Ahmed LA, Forsmo S, et al. Low serum levels of 25-hydroxyvitamin D predict hip fracture in the elderly: a NOREPOS study. *J Clin Endocrinol Metab* 2013;98:3341–3350.

[50] Thorisdottir B, Gunnarsdottir I, Steingrimsdottir L, et al. Vitamin D intake and status in 12-month-old infants at 63–66°N. *Nutrients* 2014;6:1182–1193.

[51] Åkeson PK, Lind T, Hernell O, et al. Serum vitamin D depends less on latitude than on skin color and dietary intake during early winter in Northern Europe. *J Pediatr Gastroenterol Nutr* 2016;62:643–649.

[52] Rosendahl J, Fogelholm M, Pelkonen A, et al. A history of cow's milk allergy is associated with lower vitamin D status in schoolchildren. *Horm Res Paediatr* 2017;88:244–250.

[53] Hauta-Alus HH, Holmlund-Suila EM, Rita HJ, et al. Season, dietary factors, and physical activity modify 25-hydroxyvitamin D concentration during pregnancy. *Eur J Nutr* 2018;57:1369–1379.
[54] Andersen LB, Abrahamsen B, Dalgård C, et al. Parity and tanned white skin as novel predictors of vitamin D status in early pregnancy: a population-based cohort study. *Clin Endocrinol* 2013;79:333–341.
[55] Bärebring L, Schoenmakers I, Glantz A, et al. Vitamin D status during pregnancy in a multi-ethnic population-representative Swedish cohort. *Nutrients* 2016;8:E655.
[56] Eggemoen ÅR, Falk RS, Knutsen KV, et al. Vitamin D deficiency and supplementation in pregnancy in a multiethnic population-based cohort. *BMC Pregnancy Childbirth* 2016;16:7.
[57] Hauta-Alus HH, Korkalo L, Holmlund-Suila EM, et al. Food and nutrient intake and nutrient sources in 1-year-old infants in Finland: a cross-sectional analysis. *Nutrients* 2017;9:E1309.
[58] Granlund L, Ramnemark A, Andersson C, et al. Prevalence of vitamin D deficiency and its association with nutrition, travelling and clothing habits in an immigrant population in Northern Sweden. *Eur J Clin Nutr* 2016;70:373–379.
[59] Madar AA, Klepp KI and Meyer HE. Effect of free vitamin D(2) drops on serum 25-hydroxyvitamin D in infants with immigrant origin: a cluster randomized controlled trial. *Eur J Clin Nutr* 2009;63:478–484.
[60] Madar AA, Gundersen TE, Haug AM, et al. Vitamin D supplementation and vitamin D status in children of immigrant background in Norway. *Public Health Nutr* 2017;20: 2887–2892.