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Vitamin D deficiency and sufficiency among Canadian children residing at high latitude following the revision of the RDA of vitamin D intake in 2010

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Abstract

Recently, countries at high latitudes have updated their vitamin D recommendations to ensure adequate intake for the musculoskeletal health of their respective populations. In 2010, the dietary guidelines for vitamin D for Canadians and Americans aged 1–70 years increased from 5 μg/d to 15 μg/d, whereas in 2016 for citizens of the UK aged ≥4 years 10 μg/d is recommended. The vitamin D status of Canadian children following the revised dietary guidelines is unknown. Therefore, this study aimed to assess the prevalence and determinants of vitamin D deficiency and sufficiency among Canadian children. For this study, we assumed serum 25-hydroxy vitamin D (25(OH)D) concentrations <30 nmol/l as 'deficient' and ≥50nmol/l as 'sufficient'. Data from children aged 3–18 years (*n* 2270) who participated in the 2012/2013 Canadian Health Measures Survey were analysed. Of all children, 5·6 % were vitamin D deficient and 71 % were vitamin D sufficient. Children who consumed vitamin D-fortified milk daily (77 %) were more likely to be sufficient than those who consumed it less frequently (OR 2·7; 95 % CI 1·4, 5·0). The 9 % of children who reported taking vitamin D-containing supplements in the previous month had higher 25(OH)D concentrations (OR 6·9 nmol/l; 95 % CI 1·1, 12·7 nmol/l) relative to those who did not. Children who were older, obese, of non-white ethnicity and from low-income households were less likely to be vitamin D sufficient. To improve vitamin D status, consumption of vitamin D-rich foods should be promoted, and fortification of more food items or formal recommendations for vitamin D supplementation should be considered.

Key words: Vitamin D: Supplementation: Children: Dietary reference intake: Canadian Health Measure Survey: Determinants: Canada

Although vitamin D deficiency is a health concern worldwide, vitamin D recommendations vary from country to country. It is possible to attain adequate vitamin D from cutaneous synthesis through exposure to solar radiation[1,2]; however, citizens living in high-latitude countries in North America[3–5] and Europe[6] are at risk of low vitamin D concentrations due to inadequate sun exposure[3,4,7]. Low dietary vitamin D intake due to the limited availability of vitamin D-rich natural foods[8] and poor food choices[9–11] compounds the situation. Therefore, food fortification together with supplementation are strategies suggested[2,6,12–17] for children and adults. However, milk and margarine are the only mandatorily vitamin D-fortified foods in Canada[18], and there are no formal guidelines for children >1 year to use vitamin D supplements. In the UK, dietary guidelines for vitamin D intake were not established until recently, because regular summer exposure to sunlight was considered adequate to synthesise enough vitamin D to meet year-round needs of citizens aged 4–64 years[19]. In the UK, margarine and infant formula are the only foods that are mandatorily fortified with vitamin D[6], and therefore meeting vitamin D adequacy through diet alone may be challenging.

Because of increasing evidence of both skeletal[4,20] and non-skeletal[4,7] effects of vitamin D insufficiency, various health bodies have upwardly revised their vitamin D recommendations to ensure adequate intake. In 2016, the Scientific Advisory Committee on Nutrition recommended that everyone in the UK at 4 years of age and above consume 10 μg of vitamin D daily. In 2010, the dietary intake of vitamin D for Americans and Canadians aged 1–70 years was increased from 5 μg/d as adequate intake to 15 μg/d as RDA, which is presumed to meet or exceed the vitamin D requirement of 97·5 % of the healthy population. In the same year, the estimated average requirement (EAR) was established at 10 μg, which is estimated to meet the requirements of half of the population. The recommendations presume no or minimal sun exposure[20].

Abbreviations: 25(OH)D, 25-hydroxy vitamin D; CHMS, Canadian Health Measures Survey; DRI, Dietary Reference Intake; MEC, mobile examination centre.

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Serum 25-hydroxy vitamin D (25(OH)D) concentration is the established biomarker for vitamin D status[4,21], which reflects vitamin D derived from all sources, that is, diet, supplements and cutaneous synthesis[4]. A daily intake of 15 μg of vitamin D is linked to achieving a serum 25(OH)D concentration of 50 nmol/l and an intake of 10 μg to achieving a serum 25(OH)D concentration of 40 nmol/l[20]. There is contention about the serum 25(OH)D concentration required for vitamin D sufficiency. In 2015, the Canadian Pediatric Society re-affirmed that 25(OH)D concentrations of 75 nmol/l are optimal for the prevention of a variety of childhood and adult diseases[22]. Furthermore, the Institute of Medicine[20] has stated 30 nmol/l of serum 25(OH)D as the cut-off for vitamin D deficiency for Americans and Canadians, whereas the Scientific Advisory Committee on Nutrition in the UK[19] recently decided to consider those with 25(OH)D concentrations <25 nmol/l as deficient similar to the Canadian Pediatric Society's definition[22]. For the purpose of the present study, we assumed serum 25(OH)D concentrations <30 nmol/l as deficient and >50 nmol/l as sufficient.

Whiting *et al.*[13] assessed the vitamin D status of Canadians aged 6–79 years based on serum vitamin D concentrations recommended by the 2010 Dietary Reference Intake (DRI) cut-offs of the Institute of Medicine[20] using observations collected before 2010. They reported that 25·7 % of Canadians had 25(OH)D < 50 nmol/l, with non-whites and non-supplement users having lower 25(OH)D concentrations, the latter especially in winter[13]. Socio-demographic indicators, food intake data and anthropometric variables were not examined in relation to vitamin D status. In addition, children were not examined separately from adults.

The vitamin D intake of children in some Canadian provinces is below the current EAR and RDA[23,24]. However, national data from the Canadian Health Measures Survey (CHMS) indicates that most children are vitamin D sufficient, considering that the average vitamin D concentration of children aged 6–11 years was 75 nmol/l in 2007–2009 and 67 nmol/l in 2009–2011[12,25]. In contrast, based on the higher cut-off of 75 nmol/l for sufficiency suggested by the Canadian Pediatric Society, many Canadian children have inadequate vitamin D status. It is important to estimate the prevalence of vitamin D sufficiency and have a comprehensive understanding of risk factors for vitamin D insufficiency among Canadian children based on data obtained after 2010, in order to devise prevention strategies to protect against deficiency.

In this study, we aimed to identify the prevalence of vitamin D deficiency and sufficiency among Canadian children using data obtained from the nationally representative 2012/2013 CHMS. We extended this with prevalence estimates for surpassing other commonly used thresholds (40 and 75 nmol/l). We further aimed to identify whether dietary, anthropometric, socio-demographic and seasonal factors were associated with serum 25(OH)D concentrations and vitamin D thresholds. Using this evidence, we aimed to determine which group of Canadian children is not meeting the thresholds for deficiency and sufficiency, and whether formal recommendations for vitamin D fortification and supplementation among children are required. This information might be useful for other countries in the northern hemisphere, considering whether food fortification or vitamin D supplementations should be considered for their populations.

Methods

Survey, sample design and participants

The CHMS is the most comprehensive, cross-sectional, direct health measures survey in Canada for individuals aged 3–79 years. It is led by Statistics Canada, in partnership with Health Canada and the Public Health Agency of Canada. The survey includes two parts – a home interview to gather demographic and in-depth health information, followed by the respondent's visit to a mobile examination centre (MEC) for direct physical measurements and biological specimen collection. All data were collected after receiving the participant's consent. A parent or guardian provided consent on behalf of children aged 3–13 years after receiving the child's assent to participate. Those aged 3–11 years were interviewed in the presence of a parent or guardian, who answered the questions with the assistance of the child. Additional information on the CHMS can be found on the Statistics Canada website (http://www.statcan.gc.ca).

To account for seasonality, data collection for CHMS (cycle 3) occurred from 9 January 2012 to 17 December 2013, representing Statistics Canada's standard regional boundaries: Atlantic Provinces (Nova Scotia, New Brunswick, Newfoundland and Labrador, Prince Edward Island), Quebec, Ontario, the Prairies (Alberta, Manitoba and Saskatchewan) and British Columbia. To produce reliable estimates at the national level by age group and sex, a multi-stage sampling design was used. The participants were distributed among six age groups (3–5, 6–11, 12–19, 20–39, 40–59 and 60–79 years) and sex groups (except for 3–5 years), for a total of eleven groups. For the 3–5-year age group, the survey was not designed to provide estimates for the individual's sex. Of the 360 eligible collection sites, sixteen were randomly selected using a systematic sampling method with probability proportional to each site's population size. Collection sites represented the Canadian population, east to west, with larger and smaller population densities. Next, dwellings were selected through random sampling followed by stratified sampling of inhabitants within the dwellings based on age groups[26,27]. Excluded from the survey's coverage were about 4 % of the targeted population: residents living in certain remote regions, on First Nations reserves and Aboriginal settlements, full-time members of the Canadian Forces and the institutionalised population[26,27]. A detailed description of the CHMS sampling framework is given elsewhere[26,27].

Out of 8302 individuals aged 3–79 years who were selected to participate in the survey, 7339 (88·4 %) completed the household interview and 5785 (78·8 %) later reported to the MEC. Of participants who attended the MEC, 5609 (97·0 %) were eligible to provide blood samples, whereas 176 were ineligible to provide blood samples because of medical reasons. Of the 5609 participants aged 3–79 years and eligible to provide blood, we excluded 3339 individuals. Among them were 3213 participants aged 19 years or older and 126 children who were pregnant or did not have enough blood drawn. We thus included data from 2270 children aged 3–18 years in the present study.

Serum 25-hydroxy vitamin D measurement

Serum 25(OH)D concentration in blood drawn from CHMS (cycle 3) participants was determined using the LIAISON® 25(OH)D

TOTAL assay on the Diasorin Liaison autoimmunoanalyzer (DiaSorin Ltd) using chemiluminescence immunoassay technology. The analytical detection limit was 10–375 nmol/l. Serum 25(OH)D analysis is further described in the *Vitamin D Reference Laboratory Standard Operating Procedures Manual*[28]. The between-run CV for the assay was 13·0 %. The CHMS reference laboratory precision targets for <20, 20–100 and >100 nmol/l were 15, 10 and 12 %, respectively.

We defined 'vitamin D deficiency' as those with 25(OH)D concentrations <30 nmol/l and 'meeting median requirement' as those with ≥40 nmol/l of 25(OH)D. 'Vitamin D sufficiency' was defined using two serum 25(OH)D concentration cut-offs – 50 nmol/l recommended by the Institute of Medicine as an indication of achieving the RDA of 15 μg[20] and 75 nmol/l recommended by the Canadian Pediatric Society[22].

Vitamin D-containing supplements and/or analogue use

During the household visit, participants were asked to name all prescription medications and over-the-counter and herbal remedies taken in the past month. At the MEC interview, participants were asked whether they were still taking any medications or remedies they listed at the time of the household interview, and the names of any new ones they started taking since the household interview were collected. An Anatomical Therapeutic Chemical (ATC) classification code was assigned to each medication recorded using the drug identification number (DIN). For the present study, online ATC/defined daily dose system was used to create the variable 'vitamin D-containing supplement and/or analogue use'. Those who recorded one or more of A11CC (vitamin D and analogues), A11CC01 (ergocalciferol or vitamin D_2), A11CC02 (dihydrotachysterol or synthetic vitamin D analogue), A11CC03 (alfacalcidol or analogue of vitamin D), A11CC04 (calcitriol) and A11CC05 (cholecalciferol or vitamin D_3) codes were collectively grouped as 'vitamin D supplement users'. Only individuals who reported taking the supplements during the past 1 month were considered when calculating vitamin D-containing supplement and/or analogue use in this study. When an individual used a medication that was not assigned an ATC code due to missing or not existent DIN, they were grouped as 'not stated'. The rest of the respondents were considered 'non-users'.

Vitamin D-rich foods

Food frequency data were collected as part of the household questionnaire. We considered the frequency of consumption of fish (excluding shell fish), vitamin D-fortified cows' milk (milk or flavoured milk beverages or use along with cereal), vitamin D-fortified margarine, eggs (eggs or egg dishes that include the yolk such as eggs, omelette, frittata or quiche excluding all egg dishes made with only egg whites), red meat (beef, hamburger, pork or lamb) and liver (included all types of liver such as beef, veal, pork or chicken but excluding liverwurst and liver pâté) within the previous month in the present study.

Other covariates

In addition to vitamin D-containing supplement and/or analogue use, sex, age, household income, body weight status, ethnicity and season were considered as determinants of vitamin D deficiency, sufficiency and serum concentration. Only 77 % of respondents aged 3–79 years provided household income, and therefore income imputed by Statistics Canada was used to create three categories of ≤$50 000, $51 000–100 000 and ≥$101 000 on the basis of imputation procedures found in the CHMS Data User Guide for Cycle 3[26]. Participants' standing height was measured to the nearest 0.01 mm using a fixed stadiometer (QuickMedical 235A) and body weight to the nearest 0·01 kg using a digital scale (Mettler Toledo 2256 VLC). BMI was calculated as weight by height squared (kg/m^2). Body weight status was defined using BMI as 'underweight', 'normal weight', 'overweight' and 'obese', based on the WHO classification for children and adolescents[29]. 'Underweight' and 'normal weight' categories were combined into a single category because of the small number of underweight children. Ethnicity was dichotomised as 'white' and 'non-white' (i.e., Chinese, South Asian, Black, Filipino, Latin American, Southeast Asian, Arab, West Asian, Japanese, Korean, Aboriginal and other ethnic backgrounds) on the basis of responses to the household questionnaire. Ethnicity served as a proxy for skin colour and the capacity to cutaneously synthesise vitamin D[13]. Season was categorised as 'winter' (December of the previous year, January, February), 'spring' (March, April, May), 'summer' (June, July, August) and 'fall' (September, October, November)[30] on the basis of the date of the visit to MEC to provide blood samples.

Statistical analyses

All analyses were weighted to represent national estimates of individuals aged 3–18 years in Canada and to accommodate the complex sampling design. Bootstrap weights were provided with the CHMS data. Descriptive statistics were presented as means with bootstrap standard errors and as percentage of children achieving <30 nmol/l and percentage of children achieving 40, 50 and 75 nmol/l. The associations of sex, age, household income, body weight status, ethnicity, season, food frequency (frequency of consuming fish, cows' milk, margarine, egg and red meat) and vitamin D-containing supplement and/or analogue use with vitamin D deficiency (<30 nmol/l) and sufficiency (≥50 nmol/l) were determined using multiple logistic regression. Geographic location was not significantly associated with either vitamin D deficiency or sufficiency and was excluded from the regression analyses to preserve df. The association of the above-listed factors with serum 25(OH)D concentration was investigated with multiple linear regression. The associations of vitamin D sufficiency based on the cut-off of 50 nmol/l, deficiency based on the cut-off of 30 nmol/l and the serum 25(OH)D concentration, respectively, on frequency of consuming vitamin D-rich foods (fish, cows' milk, margarine, egg and red meat) were adjusted for age, household income, season, BMI, ethnicity and vitamin D-containing supplements and/or analogue use. Liver was not included in any analysis, and milk, fish, egg, red meat and margarine consumption was grouped into two categories in the regression models because of their low frequency in the diet. To avoid small cell sizes and to preserve df, age and BMI were considered as continuous variables when dietary data were included in the multivariable models. As the present study is a secondary analysis of data from a national survey, the sample size was not powered to find out whether there were differences between groups of children for vitamin D deficiency and sufficiency. All analyses were carried out using Stata, version 14·0 (StataCorp LP). Statistical significance was defined as a P value <0.05. The Health Research Ethics Board of the University of Alberta and Statistics Canada approved this study. All processes of CHMS were reviewed and approved by the Health Canada and Public Health Agency of Canada Research Ethics Board.

Results

The mean serum 25(OH)D concentration of Canadian children in 2012/2013 was 62·2 nmol/l (95 % CI 55·8, 68·7; bootstrap SE 3·0) and the median was 62·0 nmol/l (interquartile range 47·6–74·5). The percentage of children with serum vitamin D concentrations >30 nmol/l was 5·6 % (Table 1). The percentage of children with sufficient serum vitamin D concentrations based on the 50 nmol/l cut-off was 70·9 % and based on the 75 nmol/l cut-off 23·5 % (Table 1). The mean serum 25(OH)D concentrations of children aged 3–7, 8–12 and 13–18 years were 66·9 nmol/l (95 % CI 60·2, 73·6; bootstrap SE 3·2), 63·1 nmol/l (95 % CI 56·2, 70·1; bootstrap SE 3·3) and 58·3 nmol/l (95 % CI 52·0, 64·7; bootstrap SE 3·0), respectively. Only 9·2 % of children reportedly took vitamin D supplements and/or analogues (Table 2). The most commonly consumed vitamin D-rich food was milk, with 77·2 % reporting drinking milk once a day or more frequently (Table 2). The prevalence of at least weekly consumption of milk, red meat, eggs, margarine, fish and liver was 93·0, 86·5, 72·6, 47·4, 14·4 and 1·1 %, respectively (Table 2).

Table 3 depicts the associations of socio-demographic factors, anthropometric factors, season and vitamin D-containing supplements and/or analogue use with the likelihood of meeting vitamin D deficiency and sufficiency (multiple logistic regression model) and serum 25(OH)D concentrations (multiple linear regression model). Older children (13–18 years old) were less likely to have sufficient vitamin D concentrations (meeting 50 nmol/l: OR 0·3; 95 % CI 0·2, 0·5) compared with younger children (3–7 year old). Household income was positively associated with meeting the sufficiency threshold of 50 nmol/l serum 25(OH)D. Obese children compared with underweight/normal-weight children combined were less likely to meet the sufficiency threshold (OR 0·4; 95 % CI 0·2, 0·8), as were children of non-white ethnicity compared with white ethnicity (OR 0·3; 95 % CI 0·2, 0·6). Age, non-white ethnicity and being overweight or obese were negatively associated with serum 25(OH)D concentrations, whereas household income was positively associated with it. Children were more likely to have higher serum 25(OH)D concentrations during summer and fall than in winter.

Table 1. General characteristics of Canadian children participating in the 2012/2013 Canadian Health Measures Survey

Characteristics	Weighted percentage (*n* 2270)	Deficient (%; <30 nmol/l)†	Meeting median requirement (%; ≥40 nmol/l)†	Sufficient (%; ≥50 nmol/l)†	Sufficient (%; ≥75 nmol/l)‡
All children	100·0	5·6	86·1	70·9	23·5
Age					
3–7 years	29·1	3·3*	92·6***	80·2***	28·5*
8–12 years	29·8	3·2	91·0	74·2	23·5
13–18 years	41·1	9·0	77·9	62·0	20·0
Sex					
Boys	51·6	6·8	84·8	71·6	23·1
Girls	48·4	4·3	87·4	70·2	23·9
Household income					
≤$50 000	28·5	11·3**	76·8***	55·8***	16·1*
$51 000–100 000	36·1	4·1	85·5	70·4	23·7
≥$101 000	35·4	2·6	94·1	83·6	29·3
Region of residence					
Atlantic	6·2	<1·0	90·8	78·5	22·7
Quebec	21·9	9·0	78·2	67·4	24·3
Ontario	40·0	4·3	88·3	71·1	20·9
The Prairies	19·4	5·6	89·1	76·7	30·3
British Columbia	12·5	4·6	85·8	63·7	20·1
Ethnicity					
White	63·5	2·8***	91·5***	78·6***	30·2***
Non-white§	36·5	10·5	76·7	57·6	11·8
Body weight status					
Underweight	4·9	6·8	91·7***	87·5***	27·1*
Normal weight	68·8	4·8	88·8	75·2	25·3
Overweight	14·7	6·9	85·0	61·0	23·6
Obese	11·6	8·1		51·1	11·5
Season					
Winter	20·6	14·6***	66·0***	50·5***	12·3***
Spring	30·4	3·8	88·1	67·3	12·9
Summer	25·2	3·2	92·6	78·8	31·0
Fall	23·8	2·7	93·8	84·8	38·8

χ^2 Test to determine the difference between frequencies within each characteristic: *$P<0·05$, **$P<0·01$, ***$P<0·001$.
† Based on the definition of the Institute of Medicine[20].
‡ Based on the definition of the Canadian Pediatric Society[22].
§ Non-white ethnicity included non-European and minority groups.

Table 2. Vitamin D status and intake of vitamin D-rich sources reported by Canadian children participating in the 2012/2013 Canadian Health Measures Survey

	Weighted percentage (*n* 2270)	Deficient (%; <30 nmol/l)†	Meeting median requirement (%; ≥40 nmol/l)†	Sufficient (%; ≥50 nmol/l)†	Sufficient (%; ≥75 nmol/l)‡
Vitamin D-containing supplement and/or analogue use in the previous month					
Users	9·2	5·6	84·4	70·5	23·2
Non-users	74·7	9·9	85·7	72·6	24·9
Not stated	16·1	3·2	88·6	72·0	24·2
Natural vitamin D sources					
Fish					
≤1 time/week	85·6	5·9	85·8	71·0	22·9
1–6 times/week	14·4	3·9	87·9	70·6	26·8
≥7 times/week	0·0	NA	NA	NA	NA
Eggs					
≤1 time/week	27·4	7·2	85·2	70·3	21·9
1–6 times/week	66·9	4·7	86·1	70·6	24·5
≥7 times/week	5·7	7·9	90·4	77·7	19·5
Red meat					
≤1 time/week	13·5	10·4	80·5	65·5	17·9
1–6 times/week	78·9	4·7	86·8	71·9	24·1
≥7 times/week	7·6	6·4	88·2	70·3	27·4
Liver					
≤1 time/week	98·9	5·5	86·1	71·1	23·6
>1 times/week	1·1	10·6	80·5	59·3	11·8
Fortified vitamin D sources§					
Milk					
≤1 time/week	7·0	12·3*	66·2**	52·3**	26·0
1–6 times/week	15·8	8·3	78·9	59·0	19·9
≥7 times/week	77·2	4·4	89·4	75·1	24·0
Margarine					
≤1 time/week	52·6	7·4	85·0	69·3	21·4
1–6 times/week	27·6	3·7	85·1	72·6	24·1
≥7 times/week	19·8	3·5	90·2	72·9	28·3

χ^2 Test to determine the difference between frequencies within each characteristic: * $P<0·05$, ** $P<0·001$.
† Based on the definition of the Institute of Medicine[20].
‡ Based on the definition of the Canadian Pediatric Society[22].
§ In Canada, it is mandatory to fortify liquid milk with vitamin D at 0·87–1·00 μg/100 ml. Margarine must contain at least 13·25 μg/100 g[16].

The association of vitamin D-containing supplement and/or analogue use on achieving vitamin D sufficiency was not statistically significant, but it was positively associated with serum 25(OH)D concentrations (β 5·9 nmol/l; 95 % CI 1·3, 12·1 nmol/l). Comparable with the factors associated with meeting vitamin D sufficiency based on the cut-off of 50 nmol/l, household income, age, body weight status, season and ethnicity were associated with meeting the median vitamin D requirement of 40 nmol/l, and therefore the results are not shown in Table 3.

Children who consumed cows' milk once a day or more frequently were more likely to achieve vitamin D sufficiency (≥50 nmol/l) compared with those who consumed it less frequently (OR 2·4; 95 % CI 1·7, 3·3) (Table 4). Other dietary factors were not associated with meeting sufficiency in a statistically significant manner. Higher serum 25(OH)D concentrations were found among children who consumed fish more than once a week compared with those who consumed fish once a week or less frequently, and among children who consumed margarine more than once a week compared with those who consumed it once a week or less frequently (Table 4). In addition, consumption of both milk once a day or more frequently compared with less than once a week (OR 2·8; 95 % CI 1·4, 5·6) and margarine more than once a week compared with once a week or less frequently (OR 1·5; 95 % CI 1·0, 2·2) were positively associated with meeting the median requirement (≥40 nmol/l) (the results are not shown in Table 4).

Discussion

We used nationally representative data collected in 2012 and 2013 to assess whether Canadian children, aged 3–18 years, have sufficient serum 25(OH)D concentrations and to study the determinants of vitamin D sufficiency and serum 25(OH)D concentrations following the 2010 revision of the RDA for vitamin D from 5 to 15 μg/d. We observed that 71 % of children had sufficient serum vitamin D concentrations based on the 50 nmol/l cut-off. Fewer children (23 %) met the cut-off for vitamin D adequacy of 75 nmol/l recommended by the Canadian Pediatric Society[22]. A study by Whiting *et al.*[13] based on data collected in 2007–2009 revealed that Canadians aged 6–79 years were more likely to be vitamin D insufficient if they were male, were non-white, did not supplement and when examined during winter. In 2010/2011, 88 % of pre-schoolers (2–5 years) attending daycare in the province of Montréal had vitamin D sufficiency[31]. In the present study, focusing on children and considering a wider range of potential determinants, we observed that supplement use and sex were not contributing to vitamin D sufficiency. However, we did observe that increasing age, lower household income, obesity, non-white ethnicity, the winter season and infrequent

Table 3. Associations of age, sex, household income, BMI status, season, ethnicity and vitamin D-containing supplements and/or analogue use with the likelihood of achieving vitamin D sufficiency and with serum 25-hydroxy vitamin D (25(OH)D) concentrations among Canadian children, participating in the 2012/2013 Canadian Health Measures Survey
(Odds ratios, β-coefficients and 95 % confidence intervals)

	Vitamin D deficiency (<30 nmol/l)†‡§		Vitamin D sufficiency (≥50 nmol/l)†‡§		Serum 25(OH)D concentration†‡	
Covariate	OR	95 % CI	OR	95 % CI	β	95 % CI
Intercept					57·5***	49·8, 65·6
Age						
3–7 years	Ref.		Ref.		Ref.	
8–12 years	0·8	0·1, 4·3	0·6	0·3, 1·1	–4·1*	–7·6, –0·6
13–18 years	0·2	0·0, 1·3	0·3***	0·2, 0·5	–8·6***	–10·4, –6·9
Sex						
Boys	Ref.		Ref.		Ref.	
Girls	1·4	0·5, 4·0	0·8	0·6, 1·1	0·0	–1·4, 1·4
Household income						
≤$50 000	Ref.		Ref.		Ref.	
$50 001–100 000	2·6	0·9, 7·1	1·8*	1·1, 2·9	5·1*	0·9, 9·2
≥$100 001	2·9	0·9, 9·7	3·2***	1·9, 5·3	9·1***	4·6, 13·7
Ethnicity						
White	Ref.		Ref.		Ref.	
Non-white	0·2	0·1, 0·6	0·3**	0·2, 0·6	–11·3***	–16·0, –6·6
Body weight status						
Underweight/normal weight	Ref.		Ref.		Ref.	
Overweight	1·2	0·4, 3·3	0·6	0·3, 1·2	–1·3	–5·2, 2·6
Obese	1·4	0·2, 9·3	0·4*	0·2, 0·8	–8·0***	–11·0, –5·0
Season						
Winter	Ref.		Ref.		Ref.	
Spring	3·7	0·7, 18·5	1·9	0·7, 5·2	3·0	–6·0, 12·0
Summer	6·7*	1·0, 43·4	5·5**	2·1, 14·3	15·9***	8·1, 23·7
Fall	4·1	0·9, 19·8	5·2**	2·2, 12·3	15·2**	4·2, 26·3
Vitamin D-containing supplement and/or analogue use						
Non-users	Ref.		Ref.		Ref.	
Users	1·0	0·2, 4·8	1·6	0·5, 5·9	5·9*	1·3, 12·1
Not stated	1·8	0·5, 6·5	1·0	0·5, 1·7	2·5	–0·4, 5·5

Ref., referent values.
*$P < 0·05$, **$P \leq 0·01$, ***$P \leq 0·001$.
† Results of 2270 participants aged 3–18 years were weighted to represent national estimates and adjusted for all covariates in the table.
‡ Adjusted for all other covariates in the table.
§ Based on the definition of the Institute of Medicine[20].

Table 4. Associations of vitamin D-rich foods with vitamin D sufficiency and serum 25-hydroxy vitamin D (25(OH)D) concentration, respectively, among Canadian children, participating in the 2012/2013 Canadian Health Measures Survey
(Odds ratios, β-coefficients and 95 % confidence intervals)

	Vitamin D deficiency (<30 nmol/l)†‡§		Vitamin D sufficiency (≥50 nmol/l)†‡§		Serum 25(OH)D concentration†‡	
Covariate	OR	95 % CI	OR	95 % CI	β	95 % CI
Milk						
<7 time/week	Ref.		Ref.		Ref.	
≥7 times/week	1·6	0·5, 4·9	2·4**	1·7, 3·3	4·4**	1·5, 7·4
Eggs						
≤1 time/week	Ref.		Ref.		Ref.	
>1 time/week	1·4	0·4, 4·9	1·2	0·7, 1·8	1·9	–0·8, 4·7
Fish						
≤1 time/week	Ref.		Ref.		Ref.	
>1 times/week	2·2	0·4, 11·1	1·2	0·8, 1·8	4·2*	0·2, 8·3
Red meat						
≤1 time/week	Ref.		Ref.		Ref.	
>1 time/week	1·5	0·3, 8·1	1·0	0·5, 1·9	–0·4	–5·1, 4·4
Margarine						
≤1 time/week	Ref.		Ref.		Ref.	
>1 time/week	2·8*	1·0, 7·9	1·3	0·9, 1·9	2·8*	0·3, 5·4

Ref., referent values.
*$P \leq 0·05$, **$P < 0·001$.
† Results of 2270 participants aged 3–18 years were weighted to represent national estimates and adjusted for all covariates in the table.
‡ Adjusted for age, household income, BMI, season, ethnicity and all other dietary variables in the table.
§ Based on the definition of the Institute of Medicine[20].

milk consumption were associated with vitamin D insufficiency in children aged 3–18 years.

The RDA for vitamin D is based on the assumption of minimal sun exposure; therefore, in Canada supplements, mandatorily fortified foods such as cows' milk and margarine, and natural vitamin D sources such as red meat, liver, fatty fish and egg yolks must provide nutrient adequacy in the absence of cutaneous synthesis. Our findings suggest that current food choices and supplement use are insufficient to ensure that all children maintain 25(OH)D concentrations of 50 nmol/l. Similar to previous CHMS surveys in 2007–2009[13] and 2009–2011[12], the most commonly consumed vitamin D-rich food source among children in the CHMS 2012/2013 was milk. Its frequent consumption was associated with a greater likelihood of achieving sufficiency, potentially attributable to both mandatory vitamin D fortification and the formal recommendations for daily milk consumption included in the Federal Government document, *Eating Well with Canada's Food Guide*[32]. Similar to Canadian children, the highest dietary contributor of vitamin D among British children is milk and milk products[6], despite the fact that only margarine and infant formula are mandatory fortified in the UK[6]. This could be due to low consumption of margarine by children and the promotion of milk and milk products by Public Health England in *The Eatwell Guide*[33].

Some may argue that achieving appropriate 25(OH)D concentrations through use of vitamin D supplements is more practical than through the diet for the following reasons – a higher requirement of vitamin D in obese children[2,4,34,35], lactose-intolerance limits milk consumption in some children[6,36], the cost of some natural food items rich in vitamin D may be high[37,38] and limited availability and accessibility of vitamin D-rich foods[39]. The formal recommendations for vitamin D supplement use in Canada are only for infants and those above the age of 50 years[4]. This explains the J-shaped curve of vitamin D-containing supplement use by age[40]. The present study further revealed higher serum 25(OH)D concentrations in summer and fall compared with spring and winter, reflecting that cutaneous synthesis is higher during summer months[41] due to Canada's high latitude. Therefore, formal recommendations for vitamin D supplement use for children are likely to increase their use, and consequently benefit vitamin D status and bone health mostly during winter and spring months.

We identified that the use of vitamin D-containing supplements and/or analogues was positively associated with serum 25(OH)D concentration. However, the difference between children reportedly using *v.* not using supplements and/or analogues was relatively small (6·9 nmol/l). Those who reported using supplements may not have been taking them regularly, and the amount of vitamin D present in the supplements and/or analogues may not have been enough to make a big difference. Unfortunately, we were unable to explore these reasons as the data on frequency of vitamin D-containing supplement and/or analogue use and the amount of vitamin D in the supplements and/or analogues were not available.

At present, there is a debate that the revised DRI for vitamin D is underestimated[22,42–44] or overestimated[45]. The Canadian Endocrine Society[46], the Canadian Pediatric Society[22] and the Canadian Dermatology Association[17] recommend higher intakes of vitamin D for children than that recommended by the DRI to assure sufficiency. There is evidence that the current DRI of 15 μg may not be high enough to raise serum concentrations to at least 50 nmol/l, particularly if sun exposure is limited. For example, Hall *et al.*[47] estimated that individuals of African ancestry with low sun exposure who live in California need 16·25 μg (in summer months) to 42·50 μg (in winter months) of vitamin D to achieve serum 25(OH)D concentrations of 50 nmol/l or more. This raises the question as to why the same DRI for vitamin D is established for citizens living in both Canada and the USA considering that Canadians have fewer fortified food choices than Americans and opportunities for cutaneous synthesis of vitamin D due to Canada's higher latitude. The most recent report of the Scientific Advisory Committee on Nutrition in the UK[19] recommends 10 μg of vitamin D daily for citizens of the UK at age 4 years and above, who similar to Canadian citizens live at high latitudes. The recommendation assumes minimal sun exposure. It is important to consider whether citizens are able to achieve 10 μg of vitamin D daily from food sources alone, and whether that amount is high enough to assure vitamin D sufficiency.

In our study, obese children had lower serum 25(OH)D concentrations and were less likely to be vitamin D sufficient based on the 50 nmol/l cut-off, indicating that they are not consuming the extra vitamin D that has been identified to be necessary for obese individuals to achieve vitamin D sufficiency[34,35]. Previous studies have suggested that the daily vitamin D intake for overweight and obese adults should be 1·5 times and 2–3 times higher relative to normal-weight individuals, respectively[34,35], indicating the essentiality of supplements for those with excess body weights. The authors further suggested reconsideration of the DRI serum cut-off values[34,42] and providing body weight-specific cut-offs[34]. Moreover, the Endocrine Society of Canada recommends obese children and adults take at least 2–3 times more vitamin D than that recommended for their age group[46], and the Canadian Pediatric Society[22] suggests body weight- and BMI-specific vitamin D requirements when establishing dietary requirements. On the basis of our findings, there is either a lack of awareness of the differential needs, or obese children are unable to access enough dietary vitamin D to achieve their increased requirement, or a combination of both. Furthermore, nearly 37 % of children in the present study were non-white and at increased risk for lower serum concentrations and insufficiency. Deeply pigmented skin requires a longer period of sun exposure to synthesise vitamin D or a larger area of bare skin to be exposed to UV-B radiation[47]. Therefore, the use of supplements also could help ensure vitamin D sufficiency in children of non-white ethnicity.

This study has certain limitations. We could not calculate dietary vitamin D intake, as data on the dose and frequency of intake of supplements and the amounts of food consumed were not collected. The possible misclassification of supplements or medications that contain vitamin D may have resulted in underestimation or overestimation of their use. The low prevalence of supplement users in our study resulted in a lack of statistical power to detect associations. The differences in serum 25(OH)D concentrations between supplement users and non-users indicate that the data processing method used to identify vitamin D supplement use was reasonably valid. Strengths of our study include that the CHMS followed quality control measures to maintain data quality, including for interviews, biological specimen collection and analysis. Complete and accurate data were ensured by performing data validation halfway through and at the end of data collection. Cycle 3 CHMS interview and laboratory data were compared with cycle 1 and 2, Canadian Community Health Survey, and US National Health and Nutrition Examination Survey to ensure that the data were consistent among these different data sources[27].

Conclusions

The percentage of children with serum vitamin D concentrations <30 nmol/l was 5·6 %, and the percentage of children with serum concentrations exceeding 50 nmol/l was 70·9 %. The frequency of consuming vitamin-D supplements and vitamin D-rich food, except cows' milk, was low. Older, non-white, low-income and overweight/obese children need targeted efforts to improve their vitamin D status, especially during winter months. Although supplements can raise serum vitamin D concentrations, it appears that the reported supplementation had only a modest effect on improving serum vitamin D concentrations. Establishing broader fortification protocols and formal recommendations for vitamin D supplementation, especially during winter and spring seasons, among Canadian children may be beneficial.

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