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Vitamin D Status of People 3 to 79 Years of Age from the Canadian Health Measures Survey 2012–2019

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ABSTRACT

Background: Vitamin D is recognized in bone health and the prevention of rickets and osteomalacia.
Objective: This study aimed to assess vitamin D status of people in Canada and to identify factors associated with vitamin D inadequacy and deficiency.
Methods: Serum 25-hydroxyvitamin D (25(OH)D) from the Canadian Health Measures Survey (cycles 3–6, $n = 21,770$, 3–79 y) were evaluated for geometric means and proportions <40 (inadequate) and <30 (risk of deficiency) nmol/L. Factors associated with inadequacy or deficiency were tested using logistic regression.
Results: Mean serum 25(OH)D was 57.9 (95% CI: 55.4, 60.5) nmol/L; the prevalence of inadequacy was 19.0% (95% CI: 15.7, 22.3) and risk of deficiency was 8.4% (95% CI: 6.5, 10.3). Prominent dietary factors associated with inadequacy in adults included: not consuming fish compared with ≥1/wk (adjusted OR_{adj}: 1.60; 95% CI: 1.21, 2.11), none compared with ≥1/d for cow's milk (OR_{adj}: 1.41; 95% CI: 1.02, 1.94) or margarine (OR_{adj}: 1.42; 95% CI: 1.08, 1.88); or nonuser compared with user of vitamin D supplements (OR_{adj}: 5.21; 95% CI: 3.88, 7.01). Notable demographic factors included: younger adults compared with 71 to 79 y (19–30 y OR_{adj}: 2.33; 95% CI: 1.66, 3.29); BMI ≥30 compared with <25 kg/m^2 (OR_{adj}: 2.30; 95% CI: 1.79, 2.95); lower household income quartile 1 compared with 4 (OR_{adj}: 1.46; 95% CI: 1.00, 2.15); and self-reported Black (OR_{adj}: 8.06; 95% CI: 4.71, 13.81), East/Southeast Asian (OR_{adj}: 3.83; 95% CI: 2.14, 6.85), Middle Eastern (OR_{adj}: 4.57; 95% CI: 3.02, 6.92), and South Asian (OR_{adj}: 4.63; 95% CI: 2.62, 8.19) race compared with White. Similar factors were observed in children and for deficiency.
Conclusions: Most people in Canada have adequate vitamin D status; nonetheless, racialized groups have an elevated prevalence of inadequacy. Further research is required to evaluate if current strategies to improve vitamin D status, including increasing vitamin D in fortified foods and supplements, and dietary guidance to include a source of vitamin D every day help to reduce health inequality in Canada.

Keywords: vitamin D status, Canada, population surveillance, disaggregate data analyses, health inequality

Introduction

Vitamin D is well-known for its functions in supporting bone health and the primary prevention of nutritional rickets in children and osteomalacia in adults. The most recent DRI values for vitamin D for use in the US and Canada set 400 IU/d (10 μg/d) as an Estimated Average Requirement (EAR) for people over 1 y of age [1]. In addition to dietary and supplemental sources, vitamin D can be synthesized endogenously in the skin upon exposure to solar ultraviolet B (UVB) radiation [1]. At northern latitudes, such as Canada, UVB exposure and endogenous synthesis are insufficient to support vitamin D status year-round [2]. In view of this and other considerations related to UVB, notably public health concerns about skin cancer, the DRI values for vitamin D were set in the context of minimal UVB exposure [1]. It is one of the reasons for mandatory vitamin D fortification of milk and

Abbreviations used: CHMS, Canadian Health Measures Survey; EAR, Estimated Average Requirement; LC-MS/MS, liquid chromatography tandem mass spectrometry; MEC, mobile examination center; 25(OH)D, 25-hydroxyvitamin D; UVB, ultraviolet B; VDSP, Vitamin D Standardization Program; VDSCP, Vitamin D Standardization Certification Program.

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margarine in Canada as a public health strategy to reduce the risk of vitamin D deficiency and promote adequate bone health [3].

The most widely accepted biomarker used to assess vitamin D status is serum 25-hydroxyvitamin D (25(OH)D). In North America, a serum 25(OH)D level of 40 nmol/L is considered adequate for approximately half of the population. Other 25(OH)D cutoff points for use in vitamin D assessment in North America include: 30 nmol/L as the concentration below which people are at risk of vitamin D deficiency relative to bone health; 50 nmol/L as the concentration at which almost all (97.5%) healthy people are considered sufficient; and 125 nmol/L as the level above which the risk of adverse effects increases [1].

In 2007, the Canadian Health Measures Survey (CHMS) was launched to provide detailed information on the health of people living in Canada, including vitamin D status [4]. Shortly thereafter, the Vitamin D Standardization Program (VDSP) was developed to ensure international portability and rigorous quality assurance in the measurement of serum 25(OH)D [5,6]. Vitamin D status has been reported using 25(OH)D standardized to the reference measurement procedure for CHMS cycles 1 and 2 (2007–2011) in participants 3 to 79 y [7] and cycle 3 (2012–2013) in adults [8]. To date, the modifiable and nonmodifiable factors that associate with these cutoff points have not been reported using standardized 25(OH)D for all age and sex groups. Such information would support a greater understanding of risk groups in Canada and is needed to help guide public health strategies toward achievement of adequate vitamin D status in people living in Canada.

Therefore, the objective of this report is to assess the population distribution of vitamin D status in Canada according to internationally accepted standard measurement procedures and population cutoff points in North America using cycles 3 to 6 (2012–2019) of the CHMS and to identify factors associated with vitamin D inadequacy and deficiency among those 3 to 79 y of age.

Methods

The CHMS is a cross-sectional survey conducted in 2-y cycles by Statistics Canada in partnership with Health Canada and the Public Health Agency of Canada. CHMS cycles 3 to 6 (2012–2019) were designed to be representative of the household population living in the 10 provinces. The observed population excludes persons living in the 3 territories, persons living on reserves and settlements in the provinces, the institutionalized population, and residents of certain remote regions as well as full-time members of the Canadian Forces [9]. A multistage sampling strategy was used to recruit at least 5000 persons over each 2-y cycle at 16 sites across regional strata (British Columbia; the Prairies spanning the provinces of Alberta, Saskatchewan, and Manitoba; Ontario; Québec; and the Atlantic provinces of Newfoundland and Labrador, New Brunswick, Nova Scotia, and Prince Edward Island) and considering age-group strata (3–5, 6–11, 12–19, 20–39, 40–59 and 60–79 y) [9]; latitude was not a component of the sampling design. Based on availability of a serum 25(OH)D concentration, the total sample size available for the present analyses is $n = 21{,}770$; 1301 records were missing pertinent data (i.e., not enough serum) and 91 were not applicable (phlebotomy contraindicated).

All CHMS protocols were reviewed and approved by the Health Canada Ethics Review Board (REB 2005-025H), and a full Privacy Impact Assessment was completed through the Office of the Privacy Commissioner of Canada (https://www.statcan.gc.ca/en/about/pia/chmsc3) [10]. Participants 14 y of age and over signed a consent form before their participation at the mobile examination center (MEC), and those 6 to 13 y of age signed an assent form in addition to their parent signing the consent form [4]. The interviews were conducted in either official language (English/French) or, where possible, a nonofficial language as preferred by the participant to reduce language barriers to participation.

The CHMS data are collected in 2 steps with a household in-person interview followed by a visit to the MEC for physical measurements and collection of specimens [4]. Serum samples were collected in either the fasted or fed state at the MEC; children 3 to 5 y of age were not required to fast. Samples were shipped on dry ice to the Nutrition Research Division, Health Canada for storage at -80°C until analysis. For cycle 3, total 25(OH)D was measured using an immunoassay (LIAISON Total 25OH Vitamin D, Diasorin Inc) and standardized using the VDSP as previously described [7,8]. Cycle 4 serum 25(OH)D was measured using the same immunoassay and standardized using unweighted Deming regression against liquid chromatography tandem mass spectrometry (LC-MS/MS) in 148 samples randomly selected within age, sex, region, and fasting/fed states [standardized concentration = 5.2723 + 0.9979 (immunoassay concentration) nmol/L]. For cycles 3 to 4 standardization, total 25(OH)D was measured using LC-MS/MS in the Vitamin D Standardization Certification Program (VDSCP) accredited laboratory of Health Canada [11]; the C-3 epimer of 25(OH)D was excluded. Cycles 5 and 6 samples were measured for serum total 25(OH)D according to standardized measurement procedures using the same LC-MS/MS method certified through the VDSCP as being traceable to the internationally recognized reference measurement procedures (www.cdc.gc/labstandards/vdscp.html). This laboratory has maintained certificates of proficiency from the Vitamin D External Quality Assurance Scheme since 2005, College of American Pathologists since 2012, and the VDSCP since 2015; the latter of which requires accuracy within 5% of National Institute of Standards and Technology certified reference values and precision <10%. Of the analytical sample, $n = 4$ had serum 25(OH)D < Limit of detection (LOD) (10 nmol/L); one-half LOD concentration was used in the statistical analyses.

Demographic information

The age and sex groups used in CHMS sampling were converted to the DRI life stage groups [1] to align with dietary guidance and regulatory policy. Children 3 y of age were combined with the 4–8 y group and analyzed with sexes combined as per these DRI life stage groups, consistent with previous reports [7].

Race-based identity in the CHMS was self-reported and subsequently categorized using proposed standards for race and Indigenous Peoples identity data analyses in Canada [12]. Groups were: Black (African, Afro-Caribbean, African Canadian descent); East/Southeast Asian (Chinese, Korean, Japanese, Taiwanese or Filipino, Vietnamese, Cambodian, Thai, Indonesian, or other Southeast Asian descent); Indigenous Peoples (First Nations, Inuit, and Métis persons); Latino (Latin American, Hispanic descent); Middle Eastern (Arab, Persian, West Asian descent e.g., Afghan, Egyptian, Iranian, Lebanese, Turkish, Kurdish); South Asian (South Asian descent e.g., East Indian, Pakistani, Bangladeshi, Sri Lankan, Indo-Caribbean); White (European descent); or another race category that we designated as 'other' to represent any other or multiple racial origins not already categorized. These data were analyzed to gain a better understanding of vitamin D status in relation to race to better inform actions to help reduce health inequalities [12].

Self-reported total household income data for cycles 3, 4, and 6 were used in this analysis. Missing income data were imputed by Statistics Canada [13,14]. For cycle 5, income was obtained directly from the Canada Revenue Agency's income tax files, and because of its sensitivity and confidentiality concerns, the data was only made available as income categories rather than as continuous data. Given the different methods of data collection and interpretation, household income for cycle 5 was excluded from this report; all other data from cycle 5 was used in univariate analyses combined with cycles 3, 4, and 6. Household income was adjusted for household size (total household income/square root of the household size) and subsequently categorized into quartiles as recommended [15]. Higher quartiles represent higher household incomes.

Household education, the highest level achieved by any member of the household >12 y of age, was examined using 3 categories (high school or less, postsecondary graduate, not stated). This approach is appropriate for children as most have not achieved their educational potential and some younger adults might still be pursuing education at the time of the survey.

Serum sampling variables

The sample collection date was used to estimate potential for UVB-related vitamin D synthesis and clustered into 2 categories: productive UVB period of April 1 through October 31 compared with minimal UVB November 1 through March 31 in Canada [16]. This variable was preferred over alternative approaches that use season or calendar month since some seasons and months have varied potential for UVB exposure (e.g., fall begins in September with enough UVB exposure for vitamin D synthesis and ends with minimal exposure in December). The collection sites within cycle were ordered to take into account seasonality and temporal effects [14]. Factors that impact endogenous synthesis of vitamin D, such as sun exposure, use of sunblock products, and skin pigmentation have previously been reported for adults from cycles 1 to 3 [8]. The survey questions for these factors have changed over CHMS cycles and were thus excluded from the present analysis.

In view of emerging evidence that serum 25(OH)D can be 6 to 8 nmol/L higher in the fed compared with fasting state [17,18], data were explored according to fasting/fed states. Geometric means and 95%CI for participants 6 to 79 y of age overlapped and were not statistically different (fasted: 57.2, 95% CI: 54.7, 59.8 nmol/L compared with fed: 58.2, 95% CI: 55.3, 61.2 nmol/L, $P = 0.32$), and thus the data were analyzed together regardless of fasting/fed states.

Lifestyle variables

The CHMS includes a targeted food frequency questionnaire designed to capture frequency (per day, week, month, or year) of consumption of indicator foods including some that are rich (natural or fortified) in vitamin D [4]. Foods surveyed and for which vitamin D fortification is mandated include cow's milk (fluid and powdered milk) and margarine. Fortified plant-based beverages (e.g., soya, rice, or almond) were included as these are regulated in Canada to contain the same amount of vitamin D as cow's milk. Yogurt intake frequency (excluding frozen yogurt) was collected as some products are made with vitamin D fortified milk. Consumption of any fish was surveyed. Data for fatty fish, which are rich in vitamin D, were not collected in the same manner across cycles, and thus total fish consumption regardless of type was analyzed. Food frequency data were explored using categories of none, <1, and ≥1 per day (fortified foods and yogurt) or week (fish). Surveillance methods to capture supplement use have also changed over cycles 3–6 and hence were categorized as use (yes/no) of a supplement containing vitamin D (multivitamin or single source). Dose of vitamin D in the supplement and frequency of use were not available.

BMI is a known correlate of vitamin D status [8,19] and was thus included in our analyses. For adults, BMI categories explored included: <25.0 kg/m^2 (normal weight and underweight), 25.0–29.9 kg/m^2 (overweight), and ≥30 kg/m^2 (obese). The subcategories of <18.5 kg/m^2 (underweight) and 18.5–24.9 kg/m^2 (normal weight) were combined due to small sample size ($n = 188$) in the underweight category. For children 3–18.9 y, BMI was categorized using z-scores (≤1, >1 to 2, >2) derived using the WHO Growth Standards (≤5 y) and Reference (>5 y) datasets [20].

Data for smoking (nonsmoker compared with occasional or daily smoker) were analyzed for participants ≥19 y. This variable was included based on the NHANES, in which the proportion of participants with 25(OH)D <30 and <50 nmol/L was almost double in active smokers compared to those who never smoked [21,22].

Statistical analyses

The distribution of 25(OH)D concentration from CHMS cycles 3–6 combined revealed a slight skewness to the right (skewness = 1), and the Kolmogorov-Smirnov test for normality had a P value <0.01 (Supplemental Figure 1). Because the distribution was slightly skewed and to facilitate comparison with other studies, we report geometric means. The interpretation reported herein is based on differences in geometric means among categories; least square means were compared using a univariate linear regression, in which 25(OH)D was log-transformed and differences were confirmed using t-tests with Bonferroni correction. Differences between proportions were tested using the Wald asymptotic confidence limits for each vitamin D status risk group (risk of deficiency <30 nmol/L, inadequacy <40 nmol/L, and adverse effects >125 nmol/L); alternative groups were explored (potentially inadequate 30–49.9 nmol/L and below the sufficient cutoff point of <50 nmol/L). The CIs were adjusted to allow multiple comparisons. The population proportions were deemed statistically different if the CI for the difference did not include 0. Interaction terms were not explored given the number of categories for each variable and because the goal was to first describe vitamin D status and then to test for factors associated with risk of inadequacy and deficiency.

Univariate and multivariate logistic regression was conducted for adults and children separately to explore factors associated with risk of inadequacy and deficiency. Based on the univariate analysis, smoking and yogurt intake were not statistically significant and consequently were not included in the multivariate analysis. The total number of categories of the variables selected for a multivariate analysis did not exceed the 43 degrees of freedom available based on the 4 CHMS cycles or the 32 degrees of freedom available based on the 3 CHMS cycles included in the analysis of income. Interaction terms were not explored in the logistic regression models. The models based on 3 or 4 cycles were the same except for education and income, only one of which was included in each model to avoid collinearity. Results from the goodness-of-fit tests for the multivariate logistic regression model demonstrated that the models were significant and fit the data well, explaining >80% of the variation in vitamin D status. ORs were deemed statistically significant if the CIs did not include 1.

All estimates were weighted using the sample weights to represent the Canadian population, and the standard errors were generated by the bootstrap methodology [23] using 500 bootstrap weights produced by Statistics Canada; cycle weights were adjusted for the combined cycles 3 to 6 (2012–2019) as described [24,25]. CIs for continuous variables in the descriptive analysis were based on *t*-distribution with 44 degrees of freedom, or 33 degrees of freedom for the analysis of income. As per Statistics Canada's requirements, only results with cell sizes above 5 are reported, and a coefficient of variation (CV) >16.7% is noted as high variability, in which results should be interpreted with caution [14]. We performed all statistical analyses using SAS version 9.4 (SAS Institute Inc).

Results

Vitamin D status of participants in the CHMS cycles 3 to 6 did not vary by cycle (2012–2019) whether tested as a population estimate of central tendency ($P = 0.34$), or as proportions <40 nmol/L ($P = 0.58$) or <30 nmol/L ($P = 0.66$) (Figure 1). Based on cycles 3 to 6 combined, the geometric mean concentration of serum 25(OH)D was 57.9 (95% CI: 55.4, 60.5) nmol/L with the prevalence of inadequate vitamin D status estimated to be 19.0% (95% CI: 15.7, 22.3) and 8.4% (95% CI: 6.5, 10.3) at risk of vitamin D deficiency (Figure 1, Supplemental Table 1). Vitamin D status did not vary according to the regions studied (Supplemental Table 1). In addition, 65.2% (95% CI: 61.5, 68.9) were between 50 and 125 nmol/L; and another 2.8% (95% CI: 2.0, 3.6) had serum 25(OH)D at concentrations above 125 nmol/L, which trended up across cycles. Of the 489 participants with serum 25(OH)D >125 nmol/L, the majority were White (87.7%), sampled between April 1 to October 31 (69.7%), were supplement users (65.9%), and females over 50 y (36.6%). The lowest proportions, <30 and <40 nmol/L, were among children 3–8 y and adults 71–79 y of age (Figure 2; Supplemental Table 2).

Geometric mean concentration of serum 25(OH)D and proportions in each vitamin D status category showed that males had lower vitamin D status than females (Table 1). Other sociodemographic factors associated with lower serum 25(OH)D concentrations as well as higher proportions of vitamin D deficiency included: 9–18 compared with 3–8 y in children; adults 19–70 compared with 71–79 y; participants of all self-reported races compared to White; lower household annual income quartiles 1–2 compared with quartile 4; lower household educational attainment; and recent immigration to Canada. The prevalence of inadequate status was also higher according to these demographic factors with the exception of race, in which Indigenous Peoples and Latino participants were not different from White participants. The proportions with serum 25(OH)D >125 nmol/L were lower in males, adults 31–50 y, East/Southeast Asian and Indigenous Peoples, and those with lower household education (Table 1). In view of the high variability in the estimates, the results from these univariate analyses are interpreted with caution. Alternative cutoff points (e.g., 25(OH)D <50 nmol/L) for vitamin D status showed similar patterns (Supplementary Table 3).

Among the factors related to vitamin D intakes or metabolism (Table 2), having blood drawn between November 1 and March 31 was associated with lower vitamin D status. Likewise, participants with no or low frequency of consuming fish, fortified plant-based beverages, yogurt, and margarine had lower mean 25(OH)D concentrations compared to the highest frequency group; not consuming these foods was associated with higher proportions of vitamin D deficiency and insufficiency. Compared

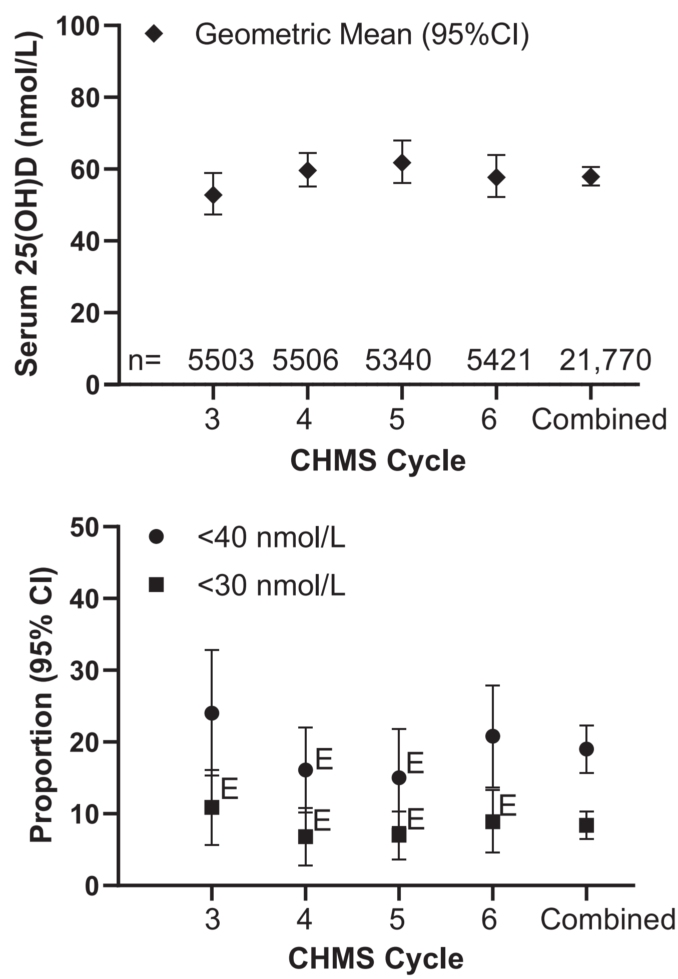

FIGURE 1. Vitamin D status of Canadians 3–79 y of age across cycles 3–6 (2012–2019) of the Canadian Health Measures Survey, n = 21,770. Values demarked with the letter E indicate coefficient of variation % >16.7, interpret with caution due to high sampling variability associated with the estimates. Proportions <40 nmol/L include those <30 nmol/L.

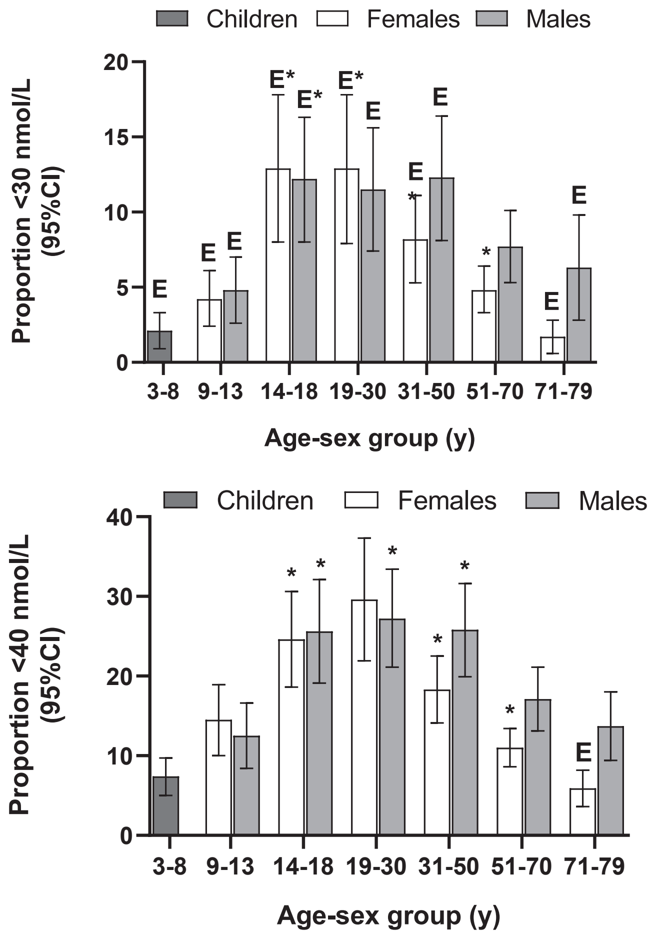

FIGURE 2. Proportion of Canadians 3–79 y of age (n = 21,770, 2012–2019) at elevated risk of vitamin D deficiency or inadequacy stratified by age–sex category. Bars demarked with the letter E indicate coefficient of variation % >16.7, interpret with caution due to high sampling variability associated with the estimates; *$P < 0.05$ vs. age–sex comparator (comparator: 9–13 y within sex for children; comparator: 71–79 y within sex for adults). Proportions <40 nmol/L include those <30 nmol/L.

to consuming cow's milk ≥ 1/d, a low frequency of >0 and <1/d was associated with lower serum 25(OH)D concentration and higher proportions in both the vitamin D deficiency and insufficiency categories, whereas not consuming cow's milk was only associated with a higher proportion of deficiency. Nonusers of supplemental vitamin D and daily or occasional smokers also had lower vitamin D status. For adults, a BMI ≥30 kg/m^2 was associated with lower serum 25(OH)D concentrations and higher proportions of inadequacy compared to BMI <25 kg/m^2, whereas a BMI 25.0 to 29.9 kg/m^2 was not different from <25 kg/m^2. For children, having a BMI z-score >1 associated with lower serum 25(OH)D concentration compared to ≤1 and having a BMI >2 z-scores was associated with higher proportions of deficiency and inadequacy. The <50 nmol/L 25(OH)D cutoff point according to these factors showed a similar pattern (Supplemental Table 4). The proportions with serum 25(OH)D >125 nmol/L were lower in participants not consuming fish, cow's milk, fortified plant-based beverages, and vitamin supplements as well as in nonsmokers and BMI ≥30 kg/m^2 for adults and for children BMI z-score >1. Vitamin D supplementation was reported in 30.9% (95% CI: 28.7, 33.1) overall, with females 51–79 y of age (53.1%; 95% CI: 48.9, 57.4) having the highest proportion across all age–sex groups (Supplemental Table 5).

In adults, factors associated with higher odds of not meeting the population target of 40 nmol/L in the multivariate logistic regression models included: being 19–50 y of age; having blood drawn during the minimal UVB period (November through March); self reporting race as any one of Black, East/Southeast Asian, Middle Eastern, South Asian, and another race except for Indigenous Peoples or Latino (with White as the reference); no or low frequency of consuming fish, cow's milk, or margarine; being a supplement nonuser as well as having a BMI ≥30 kg/m^2; and being a smoker (Table 3). Being male; 51–70 y of age; Indigenous Peoples or Latino race; lower household income quartiles 1–2; lower household education; recent immigration; and being a nonconsumer of fortified plant-based beverages and overweight were not significant in the multivariate models. Similar factors emerged in the analysis using serum 25(OH)D <30 nmol/L for risk of vitamin D deficiency. The factors associated with the risk of vitamin D deficiency in the multivariate models included: younger age 19–30 y; minimal UVB period; all races except for Indigenous Peoples or Latino; not consuming fish; no or lower frequency of cow's milk; not consuming fortified plant-based beverages; or supplements as well as having a BMI ≥30 kg/m^2.

Based on the logistic regression for children, factors that were associated with higher odds of having inadequate vitamin D status in both the univariate and multivariate models included: being between 9 and 18 y of age; having had blood drawn between November and March; all races except Latino participants (with White as the reference); lower income quartiles 1–2; lower household educational attainment; not consuming fish; lower frequency of consuming milk; no supplement use; and having a BMI z-score >2 (Table 4). Sex; household income quartiles 3; recent immigration; being a nonconsumer of milk; non- or low-consumer of fortified plant-based beverages or margarine; and overweight were not significant in the multivariate models. Similar factors were observed in the multivariate models for risk of vitamin D deficiency in children; most notably higher odds with ages 9 through 18 y; blood drawn during the minimal UVB period; all races except Indigenous Peoples and Latino participants; lower income quartiles 1–2; lower household education; not consuming fish; a frequency of consuming cow's milk <1/d (including none); and not using a vitamin D supplement.

Discussion

Assessment of vitamin D status is a priority in Canadian food and nutrition surveillance given the public health policies that have been implemented for the primary prevention of rickets and osteomalacia [3] and to promote bone health [1]. Vitamin D status of people 3–79 y living in Canada appears stable across CHMS cycles 3–6 (2012–2019) and relative to earlier reports (2007–2011) [7]. The overall geometric mean serum 25(OH)D is 57.9 nmol/L, with the prevalence of inadequate vitamin D status (<40 nmol/L) estimated to be 19.0%; 8.4% of the population are at risk of vitamin D deficiency (<30 nmol/L) and 2.8% had concentrations (>125 nmol/L), in which there may be concern for adverse effects. These nationally representative statistics

TABLE 1

Population central tendency and prevalence of vitamin D status risk groups according to sociodemographic characteristics in a univariate analysis of the Canadian Health Measures Survey data cycles 3–6[1]

Variable	*n*	Central tendency Geometric mean[2] (95% CI) nmol/L (*n* = 21,770)	Prevalence (95% CI) of vitamin D status based on serum 25-hydroxyvitamin D		
			Risk of deficiency % <30 nmol/L (*n* = 1348)	Inadequate % <40 nmol/L (*n* = 3409)	Risk of adverse effects % >125 nmol/L (*n* = 489)
Sex					
Female (comparator)	10,845	61.0 (58.5, 63.6)	7.3 (5.6, 9.0)	16.9 (14.0, 19.8)	4.2 (2.9, 5.5)
Male	10,925	55.0 (52.3, 57.8)[8]	9.5 (7.0, 12.0)[10]	21.1 (17.0, 25.1)[10]	1.3 (0.8, 1.9)[E][10]
Child age, y[3]					
3–8 (comparator)	3525	64.1 (61.5, 66.8)	2.1 (0.9, 3.3)[E]	7.4 (5.0, 9.7)	1.1 (0.5, 1.8)[E]
9–13	3100	57.2 (54.5, 60.1)[8]	4.5 (2.9, 6.2)[E][10]	13.5 (9.9, 17.1)[10]	1.3 (0.3, 2.3)[E]
14–18	2372	51.8 (48.5, 55.2)[8]	12.5 (8.9, 16.1)[10]	25.1 (20.1, 30.2)[10]	1.2 (0.3, 2.0)[E]
Adult age, y[3]					
19–30	1891	51.7 (48.6, 55.0)[8]	12.2 (8.7, 15.6)[10]	28.4 (22.6, 34.2)[10]	2.5 (1.3, 3.8)[E]
31–50	5558	54.7 (51.7, 57.8)[8]	10.2 (7.2, 13.2)[10]	22.1 (17.7, 26.4)[10]	1.6 (0.7, 2.4)[E][10]
51–70	4120	63.8 (61.2, 66.5)[8]	6.2 (4.6, 7.9)[10]	14.0 (11.2, 16.8)[10]	4.8 (3.1, 6.5)[E]
71–79 (comparator)	1204	70.2 (67.7, 72.7)	4.0 (2.1, 5.8)[E]	9.7 (7.2, 12.3)	4.5 (2.8, 6.2)[E]
Race[4]					
Black	659	40.0 (35.9, 44.5)[8]	27.2 (17.5, 36.9)[E][10]	50.9 (43.2, 58.7)[10]	X
East/Southeast Asian	1570	46.8 (42.9, 51.1)[8]	18.8 (12.6, 24.9)[10]	33.7 (26.1, 41.3)[10]	1.2 (0.0, 2.4)[E][10]
Indigenous Peoples	902	56.9 (53.4, 60.7)[9]	6.3 (2.9, 9.6)[E][10]	19.4 (13.4, 25.4)	1.0 (0.1, 2.0)[E][10]
Latino	368	50.6 (45.3, 56.5)[8]	11.5 (4.4, 18.6)[E][10]	21.6 (11.1, 32.2)[E]	X
Middle Eastern	562	43.6 (39.0, 48.7)[8]	25.1 (14.8, 35.5)[E][10]	38.9 (27.3, 50.6)[10]	1.5 (0.0, 3.2)[E]
South Asian	907	45.7 (41.0, 50.9)[8]	18.9 (13.3, 24.6)[10]	37.2 (29.1, 45.4)[10]	2.7 (0.0, 5.6)[E]
Other	1107	52.5 (49.4, 55.8)[8]	11.7 (7.2, 16.1)[E][10]	25.6 (19.6, 31.6)[10]	1.8 (0.4, 3.3)[E]
White (comparator)	15,689	62.7 (60.2, 65.4)	4.8 (3.4, 6.1)	13.3 (10.4, 16.2)	3.2 (2.3, 4.2)
Household income adjusted[5]					
Quartile 1	4204	49.9 (46.2, 53.8)[8]	14.1 (9.8, 18.3)[10]	29.7 (23.4, 36.0)[10]	2.3 (0.9, 3.8)[E]
Quartile 2	4390	56.4 (53.2, 59.7)[8]	9.5 (6.4, 12.7)[10]	22.1 (17.2, 26.9)[10]	3.2 (2.2, 4.2)
Quartile 3	4124	59.0 (55.7, 62.5)[9]	7.1 (4.4, 9.8)[E]	16.3 (12.1, 20.5)	2.7 (1.2, 4.2)[E]
Quartile 4 (comparator)	3712	62.1 (59.4, 64.9)	4.8 (2.5, 7.2)[E]	13.3 (10.1, 16.6)	2.2 (0.5, 3.9)[E]
Household education[6]					
High school or less	3544	54.4 (51.6, 57.4)[8]	11.1 (8.0, 14.3)[10]	23.3 (18.2, 28.4)[10]	1.4 (0.6, 2.1)[E][10]
Postsecondary graduate (comparator)	17,576	58.9 (56.4, 61.5)	7.6 (5.8, 9.4)	17.9 (14.8, 20.9)	3.1 (2.2, 4.0)
Not stated	650	54.6 (47.7, 62.5)	13.7 (4.9, 22.4)[E]	22.6 (12.5, 32.7)[E]	1.7 (0.2, 3.2)[E]
Recently immigrated[7]					
Yes (<5 y)	861	44.5 (40.6, 48.8)[8]	17.1 (11.7, 22.5)[10]	38.5 (30.6, 46.5)[10]	2.7 (0.0, 6.6)[E]
All others (comparator)	20,901	58.6 (56.2, 61.2)	8.0 (6.2, 9.9)	18.1 (14.9, 21.3)	2.8 (1.9, 3.6)

[1] Cycle 3: 2012–2013; Cycle 4: 2014–2015; Cycle 5: 2016–2017; Cycle 6: 2018–2019.

[2] Data are based on univariate analyses of geometric means (95% CI) or % (95% CI). Proportions <40 nmol/L include those <30 nmol/L. Geometric mean, to convert 25-hydroxyvitamin D from nmol/L to ng/ml divide by 2.496. Values demarked with the letter E have coefficient of variation % >16.7, interpret with caution due to high sampling variability associated with the estimates.

[3] Age-sex groups compared within children (3–18 y) and adults (19–79 y); X indicates $n \leq 5$, data suppressed.

[4] Categories based on the Canadian Institutes of Health Information proposed race and Indigenous Peoples identity data analyses. East/Southeast Asian ($n = 79$ Korean, $n = 394$ Filipino, $n = 83$ Japanese, $n = 802$ Chinese, $n = 212$ South East Asian); Indigenous Peoples ($n = 476$ First Nations, $n = 394$ Métis, $n = 13$ Inuit, $n = 19$ multiple Indigenous persons not living on reserves or settlements in the provinces); Middle Eastern ($n = 304$ Arab, $n = 258$ West Asian); other includes another race or multiple origins.

[5] Income variable represents self-reported total annual household income for cycles 3, 4, and 6 only. Missing values were imputed. Sample size is according to households in cycles 3, 4, and 6. Data are adjusted for household size by dividing total annual income by the square root of the number of people per household and categorized into quartiles.

[6] Education variable represents the highest level of education achieved by any member of the household over 12 y of age.

[7] Recently immigrated regardless of age, all other includes those immigrated 5 y or more prior to survey.

[8] $P \leq 0.001$ vs. comparator for each variable, adjusted for multiple comparisons using *t*-tests.

[9] $P \leq 0.05$ vs. comparator for each variable, adjusted for multiple comparisons using *t*-tests.

[10] Statistically significant difference in population proportions vs. comparator, adjusted for multiple comparisons (Wald asymptotic confidence limits for the difference does not include zero).

using standardized vitamin D assays [5,6] reflect the population of Canada.

The prevalence of inadequate and deficient vitamin D status varies according to age more so than by sex. Inadequate vitamin D status (<40 nmol/L 25(OH)D) appears to be disproportionately high, ranging from 24.6% to 29.6% in females 14–30 y, and 25.6% to 27.2% in males 14–50 y of age. In our multivariate analyses, age was associated with inadequacy and not sex. A shift toward younger adults and adolescents being identified as at higher risk of inadequate or deficient vitamin D status is also

TABLE 2

Population central tendency and prevalence of vitamin D status risk groups according to selected characteristics of participants in The Canadian Health Measures Survey cycles 3 to 6 combined[1]

Variable	n	Central Tendency Geometric Mean[2] (95% CI) nmol/L (n = 21,770)	Prevalence (95% CI) of vitamin D status based on serum 25-hydroxyvitamin D		
			Risk of deficiency % <30 nmol/L (n = 1348)	Inadequate % <40 nmol/L (n = 3409)	Risk of adverse effects % >125 nmol/L (n = 489)
UVB exposure period					
Apr 1 to Oct 31 (comparator)	13,449	62.0 (59.0, 65.2)	5.4 (3.8, 6.9)	13.4 (10.1, 16.6)	3.2 (1.9, 4.4)[E]
Nov 1 to Mar 31	8321	52.1 (49.6, 54.9)[8]	13.1 (10.2, 16.0)[11]	27.6 (23.4, 31.7)[11]	2.2 (1.2, 3.2)[E]
Fish (any type)[3]					
None	7466	53.9 (50.8, 57.1)[8]	11.2 (8.4, 14.1)[11]	23.6 (19.2, 28.0)[11]	1.6 (1.0, 2.2)[E11]
<1 >0 per week	9218	58.9 (56.0, 61.9)[9]	7.9 (5.6, 10.1)	15.3 (11.8, 18.7)	2.8 (1.7, 3.9)[E]
≥1 per week (comparator)	5086	61.5 (58.3, 64.9)	5.9 (3.9, 7.8)	17.9 (14.4, 21.3)	4.1 (2.8, 5.5)
Fortified plant-based beverages[4]					
None	17,560	57.1 (54.4, 60.0)[8]	9.2 (7.1, 11.3)[11]	20.0 (16.5, 23.6)[11]	2.5 (1.8, 3.1)[11]
<1 >0 per day	2984	59.2 (55.6, 62.9)[10]	5.7 (3.6, 7.9)[E]	15.6 (11.3, 19.8)	2.7 (0.9, 4.5)[E]
≥1 per day (comparator)	1226	65.4 (60.8, 70.3)	4.6 (2.3, 6.9)[E]	13.9 (9.1, 18.6)	6.9 (3.4, 10.3)[E]
Cow's milk[4]					
None	3789	59.4 (56.2, 62.8)	9.5 (6.7, 12.3)[11]	19.3 (15.2, 23.3)	5.0 (3.2, 6.8)[E11]
<1 >0 per day	6955	54.6 (51.2, 58.3)[8]	10.9 (8.0, 13.8)[11]	23.4 (18.9, 27.9)[11]	2.5 (1.2, 3.8)[E]
≥1 per day (comparator)	11,026	59.9 (57.3, 62.7)	5.8 (4.1, 7.5)	15.2 (12.1, 18.3)	1.8 (1.1, 2.4)[E]
Yogurt (except frozen yogurt)					
None	3769	55.4 (52.5, 58.6)[8]	10.5 (7.3, 13.7)[11]	21.9 (17.1, 26.7)[11]	2.5 (1.3, 3.8)[E]
<1 >0 per day	12,767	57.0 (54.2, 60.1)[8]	8.8 (6.6, 10.9)[11]	24.9 (19.5, 30.4)[11]	2.4 (1.4, 3.4)[E]
≥1 per day (comparator)	5234	62.8 (59.8, 65.9)	5.5 (3.6, 7.4)[E]	16.7 (13.6, 19.8)	3.9 (2.6, 5.1)
Margarine (all types)					
None	10,946	57.8 (54.6, 61.1)	9.5 (7.1, 11.9)[11]	19.8 (16.1, 23.4)[11]	3.5 (2.3, 4.7)[E]
<1 >0 per day	6141	56.5 (53.7, 59.4)[9]	8.7 (6.3, 11.0)	20.4 (16.9, 24.0)[11]	2.0 (0.9, 3.1)[E]
≥1 per day (comparator)	4683	60.2 (57.3, 63.3)	5.5 (3.4, 7.6)[E]	15.2 (11.3, 19.0)	2.1 (1.2, 2.9)[E]
Supplemental vitamin D[5]					
No	15,353	52.7 (50.0, 55.5)[8]	11.0 (8.4, 13.5)[11]	24.7 (20.3, 29.1)[11]	1.4 (0.9, 2.0)[E11]
Yes (comparator)	6417	71.5 (68.5, 74.6)	2.7 (1.5, 3.8)[E]	6.2 (4.2, 8.1)	5.8 (3.9, 7.6)
Smoking behavior ≥19 y					
Daily or occasional	2209	51.4 (48.3, 54.7)[8]	11.6 (7.7, 15.6)[E]	27.0 (20.8, 33.1)[11]	1.2 (0.2, 2.2)[E11]
Nonsmoker (comparator)	10,525	59.7 (57.1, 62.4)	8.2 (6.1, 10.2)	18.1 (14.8, 21.3)	3.5 (2.4, 4.7)
Adults ≥19 y BMI[6]					
<25 kg/m^2 (comparator)	4481	59.5 (56.7, 62.6)	9.0 (6.6, 11.5)	18.6 (14.9, 22.2)	4.0 (2.5, 5.5)[E]
25.0–29.9 kg/m^2	4577	59.8 (57.2, 62.5)	6.8 (4.8, 8.9)	17.3 (13.8, 20.7)	3.3 (2.0, 4.6)[E]
≥30.0 kg/m^2	3544	53.5 (50.8, 56.4)[8]	11.2 (8.4, 14.1)	25.1 (20.2, 29.9)[11]	1.5 (0.6, 2.3)[E11]
Children 3-18.9 y BMI[7]					
≤ 1 z-score (comparator)	6256	59.1 (56.4, 62.1)	5.7 (4.0, 7.3)	13.4 (10.1, 16.7)	1.5 (0.8, 2.2)[E]
1–2 z-score	1706	56.5 (53.8, 59.4)[9]	6.9 (4.3, 9.6)[E]	14.6 (11.0, 18.2)	0.6 (0.0, 1.2)[E11]
>2 z-score	995	49.2 (45.9, 52.9)[8]	10.9 (6.0, 15.7)[E11]	29.8 (22.3, 37.3)[11]	X

[1] Cycle 3: 2012–2013; Cycle 4: 2014–2015; Cycle 5: 2016–2017; Cycle 6: 2018–2019.

[2] Data are geometric mean (95% CI) or % (95% CI). Proportions <40 nmol/L include those <30 nmol/L. Geometric mean, to convert 25-hydroxyvitamin D from nmol/L to ng/ml divide by 2.496. Values demarked with the letter E have coefficient of variation % >16.7, interpret with caution due to high sampling variability associated with the estimates; X indicates $n \leq 5$, data suppressed.

[3] Fish (any type) expressed per week, quantity not surveyed.

[4] Fortified cow's milk and plant-based (e.g., soya, rice, or almond) beverages expressed as frequency per day.

[5] Any supplement containing vitamin D.

[6] Adult BMI according to measured weight and height.

[7] BMI for age and sex for children according to measured weight and height. BMI z-scores according to the WHO Growth Standards and reference datasets.

[8] $P \leq 0.001$ vs. comparator for each variable, adjusted for multiple comparisons using t-tests.

[9] $P \leq 0.05$ vs. comparator for each variable, adjusted for multiple comparisons using t-tests.

[10] $P \leq 0.01$ vs. comparator for each variable, adjusted for multiple comparisons using t-tests.

[11] Statistically significant difference in population proportions vs. comparator, adjusted for multiple comparisons (Wald asymptotic confidence limits for the difference does not include zero).

recognized internationally [26–28]. Public health nutrition strategies and dietary guidance may thus need to be adapted to better respond to the needs of these life stage groups.

In-depth analyses using disaggregate data beyond age and sex are called for [29] to identify population subgroups at risk of health inequality [12] and to identify the most readily modifiable factors implicated in improving vitamin D status. By combining CHMS cycles 3–6, we were able to report disaggregate race-based analyses for people living in Canada [12]. We observed that people from all races, except for Indigenous Peoples or Latino, have higher proportions with inadequate vitamin D status relative to those of White race. In our multivariate logistic regression analyses, with adjustment for other demographic information, race remained a prominent risk factor for inadequate vitamin D status. All of the race groups we assessed showed higher prevalence (6.3%–27.2%) of vitamin D deficiency compared to the prevalence in the White population (4.8%), highlighting that health disparities exit. This is similar to disaggregate race-based analyses in the United States [26], Australia [27], and the United Kingdom [30]. The range of melanin pigmentation and photosensitivity of the skin within a race is variable and complex [31], and both the amount of melanin and UVB exposure are implicated in endogenous synthesis of vitamin D [1,2]. However, such data were not consistently collected in all CHMS cycles, precluding us from including these in the assessment of vitamin D status among disaggregated

TABLE 3

Factors associated with vitamin D deficiency or inadequacy in adults ≥19 y of age based on logistic regression in The Canadian Health Measures Survey cycles 3–6[1]

Variables	Odds of deficiency <30 vs. ≥30 nmol/L		Odds of inadequacy <40 vs. ≥40 nmol/L	
	OR (95% CI)[2]	Adjusted OR (95% CI)[3]	OR (95% CI)[2]	Adjusted OR (95% CI)[3]
Sex				
Female	Reference	Reference	Reference	Reference
Male	1.39 (1.05, 1.84)	0.88 (0.64, 1.19)	1.38 (1.14, 1.67)	0.89 (0.71, 1.11)
Age at clinic visit (y)				
19–30	3.37 (1.90, 5.97)	1.97 (1.08, 3.58)	3.68 (2.59, 5.23)	2.33 (1.66, 3.29)
31–50	2.76 (1.57, 4.84)	1.43 (0.82, 2.53)	2.62 (1.95, 3.53)	1.43 (1.03, 1.99)
51–70	1.62 (0.97, 2.68)	1.21 (0.74, 1.99)	1.51 (1.14, 1.99)	1.16 (0.87, 1.54)
71+	Reference	Reference	Reference	Reference
UVB exposure period				
April-October	Reference	Reference	Reference	Reference
November-March	2.59 (1.66, 4.02)	2.58 (1.57, 4.23)	2.40 (1.66, 3.47)	2.72 (1.78, 4.16)
Race				
Black	7.30 (3.83, 13.93)	7.77 (4.03, 14.97)	7.20 (4.81, 10.78)	8.06 (4.71, 13.81)
East/Southeast Asian	4.16 (2.63, 6.58)	5.71 (3.38, 9.65)	3.02 (1.93, 4.72)	3.83 (2.14, 6.85)
Indigenous Peoples	1.35 (0.65, 2.82)	0.96 (0.40, 2.33)	1.52 (0.99, 2.35)	1.16 (0.66, 2.05)
Latino	2.07 (0.71, 6.10)	2.21 (0.72, 6.80)	1.60 (0.79, 3.23)	1.40 (0.66, 2.99)
Middle Eastern	6.60 (3.51, 12.44)	7.37 (4.19, 12.97)	4.24 (2.50, 7.20)	4.57 (3.02, 6.92)
South Asian	4.51 (2.79, 7.28)	5.71 (3.38, 9.65)	3.53 (2.35, 5.30)	4.63 (2.62, 8.19)
Other	3.01 (1.50, 6.07)	2.62 (1.10, 6.20)	2.51 (1.66, 3.80)	2.21 (1.34, 3.67)
White	Reference	Reference	Reference	Reference
Household income[4]				
Quartile 1	2.95 (1.68, 5.19)	1.55 (0.79, 3.01)	2.57 (1.87, 3.54)	1.46 (1.00, 2.15)
Quartile 2	1.91 (1.00, 3.65)	1.41 (0.67, 2.97)	1.74 (1.32, 2.32)	1.38 (1.00, 1.90)
Quartile 3	1.45 (0.81, 2.62)	1.36 (0.69, 2.68)	1.25 (0.93, 1.68)	1.15 (0.84, 1.57)
Quartile 4	Reference	Reference	Reference	Reference
Household education[5]				
High school or less	1.39 (1.02, 1.89)	1.43 (0.99, 2.06)	1.27 (1.04, 1.56)	1.19 (0.95, 1.49)
Postsecondary graduate	Reference	Reference	Reference	Reference
Not stated	2.05 (0.92, 4.58)	1.57 (0.61, 4.02)	1.32 (0.69, 2.54)	0.93 (0.51, 1.67)
Recently immigrated				
Yes (<5 y)	2.31 (1.52, 3.50)	0.83 (0.52, 1.32)	2.93 (2.03, 4.24)	1.41 (0.99, 2.01)
No (all others)	Reference	Reference	Reference	Reference
Fish (any type)[6]				
None	2.13 (1.44, 3.15)	1.98 (1.26, 3.12)	1.84 (1.47, 2.31)	1.60 (1.21, 2.11)
<1 >0 per week	1.46 (0.94, 2.26)	1.55 (0.97, 2.47)	1.29 (1.01, 1.65)	1.32 (1.02, 1.70)
≥1 per week	Reference	Reference	Reference	Reference
Cow's milk[7]				
None	1.53 (0.99, 2.37)	1.89 (1.21, 2.96)	1.22 (0.92, 1.61)	1.41 (1.02, 1.94)
<1 >0 per day	1.81 (1.21, 2.69)	1.87 (1.23, 2.82)	1.57 (1.27, 1.95)	1.54 (1.23, 1.92)
≥1 per day	Reference	Reference	Reference	Reference
Fortified plant-based beverages[7]				
None	2.26 (1.26, 4.07)	2.39 (1.28, 4.46)	1.65 (1.13, 2.41)	1.48 (0.96, 2.27)
<1 >0 per day	1.21 (0.65, 2.25)	1.16 (0.58, 2.34)	1.17 (0.73, 1.88)	1.03 (0.60, 1.74)
≥1 per day	Reference	Reference	Reference	Reference
Margarine				
None	1.82 (1.06, 3.11)	1.67 (0.90, 3.11)	1.38 (1.06, 1.80)	1.42 (1.08, 1.88)
<1 >0 per day	1.73 (1.01, 2.97	1.51 (0.84, 2.73)	1.45 (1.08, 1.94)	1.34 (1.00, 1.79)
≥1 per day	Reference	Reference	Reference	Reference
Vitamin D supplement user[8]				
No	4.67 (3.00, 7.26)	4.22 (2.58, 6.92)	5.33 (4.00, 7.10)	5.21 (3.88, 7.01)
Yes	Reference	Reference	Reference	Reference
Measured BMI[9]				
<25 (kg/m^2)	Reference	Reference	Reference	Reference

(continued on next page)

TABLE 3 (*continued*)

Variables	Odds of deficiency <30 vs. ≥30 nmol/L		Odds of inadequacy <40 vs. ≥40 nmol/L	
	OR (95% CI)[2]	Adjusted OR (95% CI)[3]	OR (95% CI)[2]	Adjusted OR (95% CI)[3]
25–29.9 (kg/m^2)	0.74 (0.55, 0.99)	0.81 (0.58, 1.13)	0.92 (0.76, 1.10)	1.11 (0.89, 1.39)
≥30 (kg/m^2)	1.27 (0.97, 1.67)	1.86 (1.31, 2.63)	1.47 (1.19, 1.81)	2.30 (1.79, 2.95)
Smoking behavior				
Daily or occasional	1.48 (1.03, 2.14)	1.47 (0.97, 2.24)	1.68 (1.30, 2.16)	1.69 (1.31, 2.19)
Nonsmoker	Reference	Reference	Reference	Reference

[1] Data are OR (95% CI). Proportions <40 nmol/L include those <30 nmol/L. Abbreviations: 25(OH)D: 25-hydroxyvitamin D; UVB: ultraviolet B.
[2] ORs from univariate analyses for combined cycles 3–6, or 3, 4, and 6 based on available income data.
[3] Multivariate ORs, adjusted for all other variables included in the column. Due to high collinearity, the main model includes education but the income does not.
[4] Income variable represents total annual household income and includes some imputed values. Data for cycles 3, 4, and 6 were self-reported. Cycle 5 data are excluded as the data was collected using different methodology (extracted by Statistics Canada from the Canada Revenue Agency File and converted to income categories). Income was adjusted for household size by dividing total annual income by the square root of the number of people per household and categorized into quartiles.
[5] Education variable represents the highest level of education acquired by any member of the household over 12 y of age.
[6] Frequency of consuming any fish expressed per week, quantity not surveyed.
[7] Fortified cow's milk and plant-based beverages (e.g., soya, rice, or almond) expressed as frequency per day.
[8] Any supplement containing vitamin D.
[9] BMI according to measured weight and height.

races. Nonetheless, in other surveys assessments according to race, sun exposure and clothing behaviors do not explain the disparities in vitamin D status [26,32].

There are many other biological, nutritional, and behavioral factors that may help to explain the disparities in vitamin D status, some of which may be more readily modified than others. The prevalence of vitamin D inadequacy and deficiency more than doubles in the period of minimal UVB from November through March, reinforcing the importance of exogenous sources of vitamin D. For example, adults who reported either infrequent or no consumption of food sources of vitamin D such as fish (OR_{adj}: 1.32-1.60), cow's milk (OR_{adj}: 1.41-1.54) or margarine (OR_{adj}: 1.34-1.42) have greater odds of inadequate vitamin D status compared to the highest frequencies, even with adjustment for other factors in the model such as supplemental vitamin D. Similarly, children who did not consume fish (OR_{adj}: 1.61) or consumed cow's milk less than once a day (OR_{adj}: 2.05) had greater odds of vitamin D inadequacy. In addition, adult nonusers of fortified plant-based beverages had more than twice the odds of vitamin D deficiency compared to those consuming them once or more per day. Even though these observations were adjusted for consumption of multiple foods containing vitamin D (fish, cow's milk, plant-based beverages, and margarine), more detailed analyses including quantitative intakes and interactions among variables are needed to better inform actions to reduce health inequality. With the recently updated regulations that approximately double the amount of vitamin D in cow's milk, fortified plant-based beverages, and margarine [33], these foods are expected to become more prominent in the primary prevention of vitamin D deficiency and inadequacy. Future research is needed to determine if interactions exist among sociocultural, food, and health behaviors and whether the changes in vitamin D fortification help to reduce health inequality in Canada.

Supplemental vitamin D is well-known to associate with higher vitamin D status. Overall, 30.9% of the study population consume supplements containing vitamin D, consistent with previous reports [8,26,34]. Adult nonusers of supplements show 5 times greater, and children 3 times greater, odds of having inadequate vitamin D status compared to supplement users. Similar observations for vitamin D deficiency are evident. Conversely, 5.8% of the supplement users present with serum 25(OH)D >125 nmol/L, the concentration above which there maybe reason for concern for adverse effects [1]. When we explored vitamin D status of supplement users and nonusers within age–sex groups, it became evident that this observation is most common among females >50 y of age. This helps to explain why the sex differences were observed only in our univariate analyses. Dietary guidance in Canada recommends that people 51 y of age and over take a daily supplement containing vitamin D [35]. Although this guidance should continue as a protective measure against inadequate vitamin D status, more information on safe dosages for long-term use may be warranted. Of note, the Prescription Drug Limit for the amount of vitamin D in over-the-counter supplements has recently increased from 1000 to 2500 IU in Canada [36].

The top 3 factors showing the greatest differences (~20 nmol/L) in serum 25(OH)D concentration reflect both nonmodifiable factors such as age (19–30 y: 51.7 compared with 71–79 y: 70.2 nmol/L) and race (Black: 40.0 and Middle Eastern: 43.6 compared with White: 62.7 nmol/L) and one of the modifiable factors, supplement use (nonuse: 52.7 compared with use: 71.5 nmol/L). Differences according to other factors are of a lesser magnitude. Similarly, the ORs for inadequate vitamin D status among adult nonusers of supplements (OR_{adj}: 5.21) exceed those associated with smoking (OR_{adj}: 1.69) or elevated BMI ≥30 kg/m^2 in adults (OR_{adj}: 2.30). Numerous reports highlight obesity as a risk factor for inadequate vitamin D status with multifactorial etiology: volume dilution and sequestration in adipose tissues, lower intakes [37], and potentially inflammation [38]. The latter is one of many factors implicated in the etiology behind lower vitamin D status in smokers [39]. In our survey, mean serum 25(OH)D in all BMI categories is in the adequate range, albeit lower 25(OH)D concentrations in those with obesity compared to those with a normal BMI. Based on NHANES, as total intakes of vitamin D increase toward the EAR, the prevalence of inadequacy and deficiency drops [26]. Whether this association is altered by having an elevated BMI is not clear in the context of our surveillance of vitamin D status as quantitative intake data are lacking.

This study has limitations to consider. The CHMS (cycles 3–6) is designed to represent >96% of the population of Canada. It does not represent population subgroups not sampled within the territories or remote regions of the provinces. Although some data regarding Indigenous Peoples are reflected in this report, these data only reflect a limited number of persons not living on reserves or settlements in the provinces. Studies specific to Indigenous Peoples are underway designed and led by Indigenous Peoples [40,41]. The CHMS methodology on food and supplement sources of vitamin D as well as latitude and sun exposure are important limitations preventing analysis of total intakes and sun exposure behavior. The use of 8 disaggregate categories for race is novel, although the sample sizes available prevented further disaggregation of the data and precluded testing for interactions with other variables. Nonetheless, the interpretation agrees with other surveillance studies [26,27].

In conclusion, vitamin D status of people living in Canada is predominantly in the adequate range with 19% showing inadequate vitamin D status. Most racial groups show evidence of health inequality based on the higher prevalence of inadequate vitamin D

TABLE 4

Factors associated with vitamin D deficiency or inadequacy in children 3–18.9 y of age according to logistic regression in The Canadian Health Measures Survey cycles 3–6[1]

Variables	Odds of deficiency <30 vs. ≥30 nmol/L		Odds of inadequacy <40 vs. ≥40 nmol/L	
	OR (95% CI)[2]	Adjusted OR (95% CI)[3]	OR (95% CI)[2]	Adjusted OR (95% CI)[3]
Sex				
Female	Reference	Reference	Reference	Reference
Male	1.02 (0.68, 1.55)	0.95 (0.62, 1.45)	1.02 (0.79, 1.31)	0.97 (0.73, 1.29)
Age at clinic visit (y)				
3–8	Reference	Reference	Reference	Reference
9–13	2.20 (1.19, 4.06)	2.20 (1.13, 4.26)	1.96 (1.54, 2.49)	2.02 (1.53, 2.65)
14–18.9	6.63 (3.49, 12.62)	7.29 (3.83, 13.88)	4.21 (3.23, 5.47)	4.42 (3.27, 5.96)
UVB exposure period				
April-October	Reference	Reference	Reference	Reference
November-March	3.25 (2.12, 4.99)	4.26 (2.67, 6.78)	2.96 (2.08, 4.22)	4.12 (2.71, 6.27)
Race				
Black	13.12 (7.82, 22.03)	17.91 (9.98, 32.14)	7.39 (4.89, 11.19)	9.95 (6.18, 16.02)
East/Southeast Asian	10.96 (6.52, 18.41)	17.69 (10.49, 29.84)	6.34 (4.45, 9.04)	9.88 (6.68 (14.61)
Indigenous Peoples	2.04 (0.76, 5.46)	2.19 (0.63, 7.64)	2.39 (1.29, 4.40)	2.59 (1.25, 5.38)
Latino	10.40 (0.64, 168.24)	8.73 (0.59, 128.81)	3.85 (0.83, 17.93)	3.06 (0.83, 11.23)
Middle Eastern	10.15 (4.95, 20.79)	15.73 (7.13, 34.68)	4.62 (2.69, 7.96)	6.86 (4.06, 11.23)
South Asian	8.65 (3.85, 19.42)	11.13 (4.70, 26.36)	7.28 (4.02, 13.18)	11.07 (6.79, 18.05)
Other	3.59 (1.80, 7.18)	4.77 (2.42, 9.40)	2.78 (1.68, 4.59)	4.23 (2.41, 7.44)
White	Reference	Reference	Reference	Reference
Household income[4]				
Quartile 1	10.43 (3.82, 28.45)	5.42 (1.87, 15.72)	5.39 (3.32, 8.74)	3.25 (2.02, 5.23)
Quartile 2	6.43 (2.10, 19.72)	5.53 (1.63, 18.82)	3.34 (2.05, 5.44)	2.64 (1.54, 4.51)
Quartile 3	3.24 (0.84, 12.54)	2.97 (0.71, 12.35)	1.71 (1.06, 2.75)	1.49 (0.86, 2.57)
Quartile 4	Reference	Reference	Reference	Reference
Household education[5]				
High school or less	2.59 (1.72, 3.89)	2.68 (1.66, 4.32)	2.37 (1.85, 3.04)	2.36 (1.74, 3.19)
Postsecondary graduate	Reference	Reference	Reference	Reference
Not stated	1.34 (0.51, 3.52)	1.44 (0.53, 3.90)	1.52 (0.85, 2.72)	1.44 (0.81, 2.54)
Recently immigrated				
Yes (<5 y)	2.83 (1.65, 4.85)	1.40 (0.69, 2.86)	2.56 (1.80, 3.64)	1.49 (0.87, 2.55)
No (all others)	Reference	Reference	Reference	Reference
Fish (any type)[6]				
None	1.94 (1.14, 3.29)	2.47 (1.43, 4.25)	1.44 (1.02, 2.03)	1.61 (1.13, 2.29)
<1 >0 per wk	0.94 (0.52, 1.70)	0.81 (0.48, 1.38)	0.86 (0.64, 1.14)	0.83 (0.58, 1.18)
≥1 per wk	Reference	Reference	Reference	Reference
Cow's milk[7]				
None	2.82 (1.51, 5.27)	2.99 (1.28, 6.98)	1.78 (1.11, 2.87)	1.92 (0.96, 3.84)
<1 per d	2.72 (1.87, 3.95)	2.45 (1.69, 3.55)	2.12 (1.62, 2.76)	2.05 (1.58, 2.68)
≥1 per d	Reference	Reference	Reference	Reference
Fortified plant-based beverages[7]				
None	1.41 (0.67, 3.00) 1.55 (0.67, 3.55)	2.03 (0.77, 5.36)	1.14 (0.69, 1.87)	1.42 (0.80, 2.53)
<1 >0 per d	Reference	2.26 (0.88, 5.81)	1.02 (0.61, 1.71)	1.26 (0.66, 2.41)
≥1 per d		Reference	Reference	Reference
Margarine				
None	1.85 (0.86, 3.98)	1.65 (0.85, 3.20)	1.48 (0.94, 2.34)	1.32 (0.86, 2.03)
<1 >0 per d	1.23 (0.55, 2.77)	1.02 (0.48, 2.17)	1.54 (0.95, 2.49)	1.38 (0.82, 2.32)
≥1 per d	Reference	Reference	Reference	Reference
Vitamin D supplement user[8]				
No	3.88 (1.35, 11.18)	2.71 (1.19, 6.17)	3.77 (2.04, 6.97)	3.36 (2.04, 5.54)
Yes	Reference	Reference	Reference	Reference

(continued on next page)

TABLE 4 (*continued*)

Variables	Odds of deficiency <30 vs. ≥30 nmol/L		Odds of inadequacy <40 vs. ≥40 nmol/L	
	OR (95% CI)[2]	Adjusted OR (95% CI)[3]	OR (95% CI)[2]	Adjusted OR (95% CI)[3]
Measured BMI[9]				
≤ 1 *z*-score	Reference	Reference	Reference	Reference
1–2 *z*-score	1.25 (0.80, 1.95)	1.18 (0.75, 1.86)	1.10 (0.83, 1.46)	0.98 (0.71, 1.37)
>2 *z*-score	2.04 (1.20, 3.47)	1.66 (0.86, 3.19)	2.74 (1.99, 3.78)	2.62 (1.79, 3.84)

[1] Data are OR (95% CI). Proportions <40 nmol/L include those <30 nmol/L. Abbreviations: 25(OH)D: 25-hydroxyvitamin D; UVB: ultraviolet B.
[2] ORs from univariate analyses for combined cycles 3–6, or 3, 4, and 6 based on available income data.
[3] Multivariate ORs, adjusted for all other variables included in the column. Due to high collinearity, the main model includes education but the income does not.
[4] Income variable represents total annual household income and includes some imputed values. Data for cycles 3, 4, and 6 were self-reported. Cycle 5 data are excluded as the data was collected using different methodology (extracted by Statistics Canada from the Canada Revenue Agency File and converted to income categories). Income was adjusted for household size by dividing total annual income by the square root of the number of people per household and categorized into quartiles.
[5] Education variable represents the highest level of education acquired by any member of the household over 12 y of age
[6] Frequency of consuming any fish expressed per week, quantity not surveyed.
[7] Fortified cow's milk and plant-based beverages (e.g., soya, rice, or almond) expressed as frequency per day.
[8] Any supplement containing vitamin D.
[9] BMI *z*-score for age and sex according to measured weight and height and WHO Growth Standards and reference datasets.

status. Dietary guidance to consume vitamin D every day through food or supplements, combined with increasing the amount of vitamin D available in the food supply, forms a multipronged approach to achieving adequate vitamin D status at the population level [35]. Future studies should investigate whether recent changes to food fortification regulations [33,42] and over-the-counter supplements [36] reduce the prevalence of inadequate and deficient vitamin D status while maintaining safety in people who regularly consume all of these sources of vitamin D. It would also be useful for future studies to evaluate whether these dietary guidance and fortification actions are helping the vulnerable groups identified to achieve vitamin D health equality.

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Author contribution

The authors' responsibilities were as follows—JD, VD, KE, LG-F, LL, CM, KS, HW: designed the research; KS, HW: oversaw the serum analyses and standardization; LL, HW: performed data analyses; JD, VD, KE, LG-F, LL, CM, HW: wrote the paper; VD, LL, HW: had primary responsibility for the final content; and all authors: read and approved the final manuscript.

Data Availability

Data described in the manuscript, user guide(s) and data dictionary are available upon request at https://www.statcan.gc.ca/en/survey/household/5071 and https://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5071&lang=en&db=imdb&adm=8&dis=2. This research will be available in part as a public bulletin available in at the following website: The Daily — In the news: Statistics Canada's official release bulletin. (statcan.gc.ca)

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Appendix A. Supplementary data

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