25-Hydroxyvitamin D in Canadian adults: biological, environmental, and behavioral correlates

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Abstract

Summary—We assessed vitamin D status and its correlates in the population-based Canadian Multicentre Osteoporosis Study (CaMos). Results showed that serum 25-hydroxyvitamin D levels <75 nmol/L were common. Given Canada's high latitude, attention should be given to strategies for enhancing vitamin D status in the population.

Introduction—Inadequate vitamin D has been implicated as a risk factor for several clinical disorders. We assessed, in a Canadian cohort, vitamin D status and its correlates, based on serum 25-hydroxyvitamin D [25(OH)D], the best functional indicator of vitamin D status.

Methods—We studied 577 men and 1,335 women 35+ years from seven cities across Canada in the randomly selected, population-based Canadian Multicentre Osteoporosis Study (CaMos). Participants completed a comprehensive questionnaire. Serum 25(OH)D was measured by immunoassay. Multivariate linear regression modeling assessed the association between 25(OH)D and determinants of vitamin D status.

Results—Participants (2.3%) were deficient in 25(OH)D (<27.5 nmol/L); a further 18.1% exhibited 25(OH)D insufficiency (27.5–50 nmol/L). Levels <75 nmol/L were evident in 57.5% of men and 60.7% of women and rose to 73.5% in spring (men) and 77.5% in winter (women); 25(OH)D <50 nmol/L was 10% year round for those supplementing with 400 IU vitamin D/day but was 43.9% among those not supplementing in winter and spring. The strongest predictors of reduced 25(OH)D for both men and women were winter and spring season, BMI 30, non-white ethnicity, and lower vitamin D supplementation and its modification by fall and winter.

Conclusions—In this national Canadian cohort, vitamin D levels <75 nmol/L were common, particularly among non-white and obese individuals, and in winter and spring. Vitamin D intake through diet and supplementation and maintenance of normal weight are key modifiable factors for enhancing vitamin D status and thus potentially influencing susceptibility to common chronic diseases.

Keywords

Introduction

Vitamin D is synthesized via ultraviolet irradiation of the skin or from food or supplements. It is then converted in the liver to 25-hydroxyvitamin D [25(OH)D], which is the most abundant circulating form of the vitamin [1]. Serum 25(OH)D has been recognized by the 1997 Institute of Medicine committee as the best functional indicator of vitamin D status [2], reflecting the sum of cutaneous synthesis and oral intake.

There is a critical requirement of vitamin D for bone and mineral homeostasis, and in particular in preventing rickets and osteomalacia [3]. Inadequate vitamin D has been implicated in increasing the risk of osteoporosis [4], cardiovascular disease [5], diabetes [6], cancer [7–9], and autoimmune diseases such as multiple sclerosis [10].

There is concern regarding the potential for vitamin D insufficiency in the Canadian population. Endogenous synthesis of vitamin D is minimal from October to March due to Canada's high latitude and may be further limited in those with increased skin pigmentation. A number of Canadian studies have found a relatively high prevalence of 25(OH)D levels <75 nmol/L [11, 12], particularly in non-whites [13–15] and the elderly [16]. Seasonal variation was evident, with low 25(OH)D (<50 nmol/L) approximately 60% to 120% higher during winter and spring seasons [11, 15, 16]. The Canadian Health Measures Survey (CHMS) launched by Statistics Canada in partnership with Health Canada and the Public Health Agency of Canada, concurred, in a recent report, in finding lower levels of 25(OH)D between November and March and in those with darker skin pigmentation [12].

To date, there has been no Canadian national study investigating a broad range of purported biological (age, sex, ethnicity, body mass index (BMI)), behavioral (vitamin D from diet, supplements and medications, activity, sunscreen use), and environmental factors (season, sun exposure) to determine which may be independently associated with vitamin D status. The purpose of this study was to assess vitamin D status based on the distribution and seasonal variation of 25(OH)D in a national cohort of Canadian adults   35 years and examine the multivariable relationship between vitamin D status and factors which might be associated with it in this population.

Methods

Data source and subjects

Data for this study come from the Canadian Multicentre Osteoporosis Study (CaMos), an ongoing longitudinal, population-based cohort study in nine Canadian city-based centers. It includes 9,423 non-institutionalized, randomly selected men and women aged 25 years and older on entry into the study in 1995–1997; 42.5% of eligible household participants completed the full survey and 27.5% refused. A further 30% completed a refusal questionnaire which included demographic, fracture, and osteoporosis information. The full responders were found to be similar, with respect to risk factors for osteoporosis, to those additional individuals who only partially participated. Non-response bias was, therefore, negligible with respect to bone health, which is affected by 25 (OH)D concentration, and

was of concern only slightly in very elderly women and men (over 80 years of age) [17]. For a more detailed description of CaMos, see Kreiger et al. [18].

The analyses for this cross-sectional study are of data and sera gathered from participants at seven centers (Vancouver, Calgary, Saskatoon, Toronto, Kingston, Quebec City, and Halifax) between 2005 and 2007 (at 10-year follow-up) are restricted to adults aged 35+ years. A small proportion of participants (5.8%, n=110) were assessed after 2007. Of those eligible to participate at year 10 follow-up, the full survey completion rate for these seven centers was 83.1%. When excluding known deaths after baseline (1995–1997), 66.2% of the participants from the previous seven centers were still in the study after 10 years. The cohort included the 577 male and 1,335 female full participants who gave blood samples, were measured for height and weight, and completed a comprehensive questionnaire which included data on demographics, diet and supplement use, sun exposure, and physical activity. Partial participants who did not give blood were excluded.

All participating centers received ethics approval to participate in the blood and urine collection project. Signed informed consent was obtained from all participants who agreed to give samples.

Blood collection and serum 25(OH) vitamin D

All sera were analyzed at the same laboratory, using the identical technique, between March and September 2009. Fasting blood samples from participants had been aliquoted and stored at −80°C. Serum total 25(OH)D was measured using the Liaison (Diasorin Incorporated) assay, which employs chemiluminescent immunoassay technology. The detection limit was 10 nmol/L; linearity <375 nmol/L; inter-and intra-assay variability were 2.9–5.5% and 6.3–12.9%, respectively. In addition to quality controls supplied by Diasorin, external quality controls of low, intermediate, and high levels of 25 (OH)D (Biorad Laboratories, Irvine, Ca) were always used as the samples were run on the instrument. Multiple repeat determinations using the three different standards were performed over the relatively short period that the samples were assayed, and assay drift was found to be negligible. The laboratory participates in the international Vitamin D External Quality Assessment Scheme which aids in harmonizing 25(OH)D assays among different laboratories [19]. We also performed a small assessment using the standard reference material in human serum (SRM 972) from the National Institute of Standards and Technology (NIST), NIST SRM-972 level 1, that is suitable for analysis by immunoassay [20, 21]. Overall, therefore, it is unlikely that the assay drifts noted by the Center for Disease Control and the National Center for Health Statistics in their technical advisory on the Diasorin assays [22] affect the comparability of the values in this study.

Vitamin D status was categorized by three commonly used cutoffs and definitions of serum 25(OH)D: deficient <27.5 nmol/L [2] and insufficient 27.5–49.9 nmol/L [23–25]. Suboptimal included all measured levels <75.0 nmol/L, and optimal, 75 nmol/L [25–27].

Seasonality

Winter was defined as January through March, spring as April through June, summer as July through September, and fall as October through December.

Skin pigmentation

Race/color (ethnicity) was dichotomized to "white" and "other" as proxies for lighter and darker skin pigmentation. The "other" category included black (African, Haitian, Jamaican), American aboriginal, Asian (e.g., Chinese, Vietnamese, Japanese), Latin American, Arab, or Middle Eastern (e.g., Armenian, Turkish, Egyptian).

Vitamin D intake from the diet, supplements, and medications

Dietary vitamin D intake was estimated from reported usual intake of vitamin D-fortified fluid milk, soya beverage, and yogurt. This was collected using an interviewer-administered abbreviated semiquantitative food frequency questionnaire (FFQ). Milk (primarily) and milk products are the main sources of vitamin D in the Canadian diet, contributing 49% of dietary vitamin D [28]. The content in vitamin D was calculated using Canada's Food and Drugs regulations on fortification standards and vitamin D quantity from food labels. Vitamin D was categorized as no vitamin D from diet, from 1–200 or >200 IU/day. Participants were asked to bring medication and supplements used regularly. The vitamin D content of medication and supplements was determined using Health Canada's drug product database [29]. Supplement and medication intake was summed and categorized as none, from 1–400 or >400 IU/day. Details related to food and supplement data collection were previously reported [30].

Sun-related variables

Sun exposure was estimated using the question, "In the past 12 months, did you ever expose a considerable part of your body to direct sunlight?" The possible answers to the sun exposure question were never, seldom, regularly, and often. A considerable part of the body was defined as an exposure for 30 min or more in a swimsuit or equivalent without sunscreen. The sunscreen question was "In the past 12 months, have you used sunscreen or face cream with SPF to protect your skin against sunlight?" Possible responses were no, sometimes, usually, and always. We confined the interval to 12 months to facilitate recall of the participants regarding sun exposure and sunscreen use.

Statistical analyses

25(OH)D levels found to be "<10 nmol/L" were fixed to 10 nmol/L in the database. By design, CaMos oversampled older participants and also oversampled women. Using the 2006 Canadian census data, and keeping the same total sample size (n=1,912), weights were generated and applied to all our full participants in order to represent the Canadian age and sex distribution. Therefore, all results reported as frequencies or averages (and standard errors) were weighted to the Canadian population using the 2006 Canadian census data, with the exception of sample characteristics where both weighted and non-weighted results are reported on the same participants. Logistic regression was used to determine characteristics that were associated with full participants versus partial participants. Differences were noted to be statistically important if 95% confidence intervals excluded 1. Multivariable linear regression modeling was used to assess the association between 25(OH)D levels and possible determinants of vitamin D status. The variables included vitamin D intake from selected dietary sources, supplements and medication, sun exposure, sun-screen use,

sociodemographic characteristics (age group, "white" or "other" ethnicity, education, family income), BMI (weight (kg)/height (m^2)), season of blood draw, center, participation in a regular program or activity, walking, smoking, alcohol intake, and energy expended per day. Prior to the multivariable regression modeling, correlations and univariate associations between the variables and 25(OH)D were examined to refine the list of predictors identified above, removing any for which there was no evidence to support their inclusion. Interactions between body mass index and season and between vitamin D supplementation and season were investigated. All analyses were performed using SAS 9.1 (Cary, NC, USA).

Results

Description of the study participants

In total, 5,569 individuals participated in the 2005–2007 CaMos survey, of which 4,283 were part of the seven centers collecting blood. Of these, 1,912 (44.6%) were full participants who gave blood samples. When excluding known deaths after baseline, 29.6% of the original CaMos sample donated blood at year 10. Respondent characteristics are summarized in Table 1.

Differences between full participants and partial participants (those not giving blood) were examined. There were no statistically significant differences between the two groups with regard to "white" or "other" ethnicity, use of sunscreen, vitamin D intake from supplements and selected vitamin D fortified foods, and participation in regular activity. Those willing to participate fully were more likely to be female, aged 51 to 70 years (versus 35 to 50 years), have a BMI of 25 to <30 (versus BMI <25), to have less than a high school education (versus high school or trades), report often getting sun exposure (versus never), be married/partnered versus single, separated, or divorced. Some aspects were potentially biased in favor of higher values, e.g., often getting sun exposure while others were in favor of lower values, e.g., more full participants over age 50 years. For others, the effect is variable or unknown: e.g., sex, education.

Normative data

Serum 25(OH)D distributions (Table 2) and means for males and females aged 35+ years were similar. Younger males, 35–50 years, however, exhibited higher median levels than those 51–70 and 70+ years (77.1 versus 66.7 and 68.5 nmol/L, respectively). Females exhibited similar median levels over all age groups. Among all participants, serum 25(OH)D values ranged from 10 to 212.1 nmol/L.

Vitamin D status

Vitamin D status is given in Table 3. Suboptimal levels of serum 25(OH)D (<75 nmol/L) were evident in 57.5% of males and 60.7% of females. This varied for males of different age groups with the lowest prevalence of values <75 nmol/L being 50.0% for those 35–50 years; the highest prevalence was 65.5% for 51–70-year-olds. For females, this prevalence was more stable over age, ranging from 59.1% to 62.5%.

Serum 25(OH)D in the deficient range (<27.5 nmol/L) was low in the total group at 2.3%. An additional 18.1% exhibited 25(OH)D in the insufficient range (27.5–50 nmol/L).

Variability of 25(OH)D by month of year and season

25(OH)D varied over the course of the year (Fig. 1a, b). The percent with 25(OH)D levels 75 nmol/L sharply increased in July, reaching 66.9% for males and 61.5% for females. In the month of April, the percentage with 25(OH)D levels 75 nmol/L decreased to 16.4% for males and 5.3% for females. Deficient or insufficient level (<50 nmol/L) prevalence was lowest from July to October for males (1.0–11.5%) and in July (3.9%) and August (5.3%) for females. Peak prevalence of insufficiency/deficiency occurred in January (36.9%) for males and December (45.3%) for females.

When months were grouped into "seasons," the prevalence of 25(OH)D levels 75 nmol/L peaked for both males and females at 59.0% and 54.3%, respectively, in summer and were lowest in spring for males (26.5%) and in winter for females (22.5%). The prevalence of levels <50 nmol/L was greatest in the winter and spring for males (30.9–33.7%) and in fall, winter, and spring for females (25.5%, 26.1%, and 22.7%, respectively). As expected, lowest levels were observed in the summer for both males and females (5.7% and 8.7%, respectively).

Factors associated with lower 25(OH)D levels

Elevated BMI and low/no vitamin D supplementation were among the strongest risk factors for lower 25(OH)D. Among females with BMI <25, 25–29.9 (overweight), and 30 (obese), 25(OH)D <50 was 15.7%, 21.0%, and 29.1%, respectively. For males, estimates were 13.4%, 23.9%, and 20.2%, respectively; 38.7% of males and 57.5% of females supplemented their diet with vitamin D to some degree. Milk, soy beverages, and yogurt accounted on average for 48.1% of the vitamin D intake (from milk, soy beverages, yogurt, supplements, and drugs). In winter and spring, of those taking no supplementary vitamin D, at least 40% had insufficient 25(OH)D concentrations (<50 nmol/L; Table 4), the overall percentage in winter and spring being 43.9. Although the prevalence of 25(OH)D <50 nmol/L was low in summer, it was higher for those taking no vitamin D supplement. The prevalence of 25(OH)D <50 nmol/L was at or below 10% year-round among those who took a vitamin D supplement at or above 400 IU/day.

In sex-specific multivariate linear regression analyses, several independent factors predicted 25(OH)D levels (Table 5). Degree of vitamin D supplementation, together with its modification by season, were important contributors to 25(OH)D level. The greatest effects of this interaction were evident in fall and winter. Ethnic background as "other," winter and spring season, and BMI 30 (obese) were strongly associated with lower levels for both males and females. For females, determinants also included the following: BMI of 25–30 (overweight); not often exposing a considerable part of the body to sunlight; lower intake of vitamin D from supplements and fortified milk, soy beverages, or yogurt; and lack of regular activity. For males, the interaction between vitamin D supplementation and spring season was associated with higher 25(OH)D. Age and sunscreen use were not identified as independently associated factors.

Discussion

If associations between vitamin D levels and several chronic diseases are determined to be causal, then achieving and maintaining optimal vitamin D levels would represent a major correctable goal for ameliorating a number of common and debilitating diseases. In this study, levels of serum 25(OH)D <75 nmol/L [22] were evident in 59% of Canadians. Overall estimates of 25(OH)D levels, however, may be misleading, as they are derived by averaging blood samples drawn over the high and lower risk seasons. Thus, in our study, in winter and spring, nearly one third of males and one quarter of females had insufficient or deficient concentrations of 25(OH)D (<50 nmol/L), and in spring, approximately three quarters of males and females displayed 25(OH)D levels <75 nmol/L. These results are consistent with the seasonal variability noted in other Canadian studies [11, 12, 15, 31] and in other countries [32]. Consequently, it is likely that a large proportion of Canadians would have suboptimal vitamin D status at some point during the year.

The prevalence of vitamin D insufficiency and suboptimal level is dependent on the definition used (usually <50 or <75 nmol/L, respectively), and there are currently no standard international reference levels for insufficient and optimal status. The Institute of Medicine is currently reviewing vitamin D requirements and associated 25(OH) D cutoff points for health outcomes. Part of the uncertainty over defining levels of insufficiency may reside with standardization and operator variability in 25(OH)D assays [33], because a variety of methods to measure 25(OH)D are available and different extraction procedures are used. Irrespective of the assay used, as serum 25(OH)D levels falls, levels of parathyroid hormone (PTH) in the serum increase. Consequently, a standard definition of an optimal 25(OH)D level has been the concentration above which serum PTH levels cannot be suppressed further. Estimates of optimal 25(OH)D concentrations reached using the PTH suppression criterion vary widely. Overall, however, the minimum level considered by many to be optimal is 75 nmol/L [1, 26, 27], and 59% of subjects in our study fell below this threshold.

Both the current study and the report recently released by Statistics Canada from the 2007–2009 CHMS [12] included participants from the five regions of Canada—Atlantic, Quebec, Ontario, Prairies, and British Columbia. Both national surveys included sites with larger and smaller population densities. CaMos included seven sites and CHMS included 15. Both studies did not include residents of Indian reserves, those in remote northern regions, and those in institutions. The studies differed with respect to age groups. The age focus of CHMS was 6 to 79 years whereas that of this CaMos study was adults aged 35 and over. In the CaMos study, there was particular strength (i.e., unweighted numbers of participants that exceeded that of corresponding CHMS groups) for 51–70-year-old females, males that were 70 years and older, and females that were 70 years and older. Females were overrepresented in the CaMos sampling to allow for sufficient sample size to estimate factors related to osteoporosis. The CaMos age groups for the present study were chosen to correspond with those used for the Dietary Reference Intakes (DRI). Because of this, other studies which examine adequacy of vitamin D intake (which vary by DRI age group) can be easily compared with the results of CaMos. In both studies, participants within their respective age groups were weighted to represent the Canadian population. For those participants age 40 to

79, both the CaMos and CHMS studies showed similar mean 25(OH)D levels, and similar percentages of participants age 40 to 79 had 25(OH)D levels 75 nmol/L. Median values were below 75 nmol/L in most age–sex groups in our study as well as in adults in the CHMS [12]. The exceptions to this were males age 35–50 years in our study (median 77.1 nmol/L). Similar percentages (below 3%) of 25(OH)D levels <27.5 nmol/L were also noted in women aged 40 to 59 and men aged 60 to 79. In CaMos, greater numbers of women in the 60–79-year group allowed for an estimate of women with deficient (<27.5 nmol/L) levels (below 3%) whereas this estimate was not possible in CHMS due to their extreme sampling variability or small sample size. Additionally, fewer men aged 40–59 in the CaMos study had levels <27.5 nmol/L than in the CHMS study (below 3% versus approximately 6%, respectively). Twenty percent in our study had values below 50 nmol/L, whereas this percentage was not determined in the CHMS study.

In our study, among males aged 35–50 years, median 25 (OH)D was approximately 10 nmol/L higher than for those aged 50+ years. This is consistent with findings of decreased cutaneous production of vitamin D_3 with age [34, 35]. Median 25(OH)D was not higher for females aged 35–50 years. This may be related to dietary intake and/or supplement use or to other external issues, and further studies are required to explore this. In other studies, lower [36, 37], similar [13], and higher [12] 25(OH)D levels have been noted in women compared to men.

Both CaMos and CHMS studied the seasonal influences on 25(OH)D levels and vitamin D consumption from dietary sources. CHMS considered two seasons of blood collection (November to March and April to October) whereas CaMos extended the CHMS findings by studying seasonal variation of 25(OH)D in more detail, i.e., by month and by four seasons. CHMS estimated frequency of consumption of milk/enriched milk substitutes using a non-quantitative FFQ, whereas CaMos extended these findings by using a semiquantitative FFQ to estimate dietary intake of vitamin D from milk/enriched milk substitutes, as well as enriched yogurt. Furthermore, in contrast to CHMS, CaMos also addressed the use of vitamin D supplements, body mass index, sun exposure, sunscreen use, and physical activity. The CaMos results, therefore, are comparable to the CHMS results with respect to mean 25OHD levels and percentages of participants with 25(OH)D levels 75 nmol/L but extend the CHMS findings by having increased power to assess low 25(OH)D levels in older women and men, by investigating more predictors of 25(OH)D and by using a multivariable analysis (rather than a bivariate analysis) to determine independent effects of the factors.

"Other" ethnicity, a proxy for darker skin pigmentation in this study, was a strong and independent risk factor for low 25(OH)D in the CaMos study. This finding concurs with other Canadian studies [12, 13, 15, 38–40] and with international [32] findings. The population of Canadians with darker skin pigmentation now stands at one in five Canadians, and the need for people of darker skin to take more vitamin D is increasingly recognized [41].

Overweight and obesity have been rising among adults [42, 43] and children [44, 45] in Canada, particularly over the past 35 years. Adiposity is a risk factor for low 25(OH) D [11], perhaps due to sequestration of fat-soluble vitamin D in adipose tissue [46]. Excess

adiposity was an independent predictor of low 25(OH)D in this study. Obesity alone was predictive for males and females in our study, but being overweight was predictive for females only. This is consistent with studies among youth in Canada [47] and New Zealand [48] in which an inverse association between serum 25(OH)D and higher BMI was observed in females but not males. This may be related to the greater amount of body fat per unit weight among females compared to males [49] which can serve as a depot for the fat soluble vitamin D. In our study, regular physical activity was a surrogate to estimate time spent outdoors, and lack of regular activity was associated with reduced 25 (OH)D for females. However, physical activity may have benefits on 25(OH)D independent of exposure to the outdoors.

In our study, the effect of vitamin D supplementation was highly modified by season. Fall and winter supplementation, in particular, emerged as independent predictors of 25(OH)D concentrations. Low intake of vitamin D supplements (<400 IU/day) had the least impact in summer; however, 400 IU or more was needed to keep 25(OH)D above 50 nmol/L year round in 90% of participants. Few foods naturally contain vitamin D, and our study would confirm that Canadians appear to be dependent on fortified dietary sources or supplements to maintain vitamin D status.

Strengths of this study are that it offers a recent, large sample of adults, and data on an array of biological, behavioral, and environmental correlates. It uses a randomly selected sample of Canadians, from predominantly urban sites across Canada. A limitation of the study is that non-whites are underrepresented, likely due to their lower proportion in the population at entry into the study in 1995–1997. Furthermore, self-reported ethnicity was used as a proxy to surmise variations in skin pigmentation. Nevertheless, "other" (non-white) ethnicity was identified as an independent risk factor in the multivariate analysis because of the strong effect of this characteristic. Another limitation is that seasonal effects were studied using cross-sectional data instead of multiple measurements in the same person. Questions on sun exposure, although limited, were included to provide a relative estimate of sun exposure rank. Household non-response bias related to bone health was slight, although some may still have been evident [17]. In this study's sample, the response rate of the full participants (who gave blood samples) was modest, but there was no overt bias toward low or high values when full and partial participants were compared. The results for this study are based on cross-sectional data; therefore, it is not possible to infer causal links for some determinants of low vitamin D.

In summary, while frank deficiency was low in the population, combined deficient and insufficient levels (<50 nmol/L) affected one in five Canadians adults 35 years of age or older. Specific risk groups include those with excess adiposity and darker skin pigmentation. Seasonal variation had strong effects on 25(OH)D levels: vitamin D levels <75 nmol/L approached and surpassed 75% for several months in winter (for females) and spring (for males). Vitamin D supplementation was a strong determinant of 25(OH)D level, and 400 IU/day was highly protective against levels below 50 nmol/L. Achievement of adequate vitamin D intake through diet and supplementation, particularly during the winter and spring months, and maintenance of normal weight appear to be key modifiable factors to consider when developing strategies for enhancing vitamin D status in the population.

Acknowledgments

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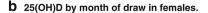9. Holick MF. Calcium plus vitamin D and the risk of colorectal cancer. N Engl J Med. 2006; 354:2287–2288.

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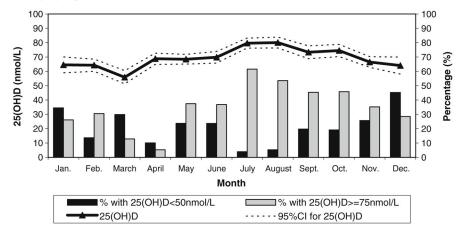
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a 25(OH)D by month of draw in males.

b 25(OH)D by month of draw in females.

Fig. 1.
a 25(OH)D by month of draw in males. **b** 25(OH)D by month of draw in females

Table 1

Descriptive statistics of full participants

Variable	Categories	Unweighted (%)		Weighted[a] (%)	
		Males (n=577)	Females (n=1,335)	Males (n=914)	Females (n=998)
Age group	35–50	10.6	6.6	43.9	42.3
	51–70	49	51	41.9	39.4
	>70	40.4	42.4	14.2	18.3
Ethnicity (versus other)	White	93.1	96.4	92.9	96.1
Body mass index	<25	29.1	38	28.4	47.3
	25–30	49.2	36.6	52.3	27.7
	30	21.7	25.4	19.3	25
Season	Winter	20.3	19.2	14.3	15
	Spring	28.6	31.4	28	24.5
	Summer	22.2	22.9	24.7	26
	Fall	28.9	26.5	33	34.5
Sun exposure	Never	35.4	45.2	27.7	38.9
	Seldom/Regularly	57.7	50.4	67.8	56.5
	Often	6.9	4.4	4.5	4.6
Sunscreen use	No	49.2	31.6	35.9	22.4
	Sometimes	22.9	22.1	27	24.1
	Usually/Always	27.9	46.3	37.1	53.5
Vitamin D intake from supplements	None	57.8	32	61.3	42.5
	0–400 IU	26.9	30.3	27.6	31.7
	>400 IU	15.3	37.7	11.1	25.8
Vitamin D intake from milk, yogurt, or soy beverage	None	9.2	11	8.3	11
	0–200 IU	74.7	71.2	69	70.8
	>200 IU	16.1	17.8	22.7	18.2
Participation in regular activity/program	Yes	53.4	54.8	56.2	51.7
Center	Vancouver	4	6.6	2.6	5
	Calgary	20.5	19.2	26.5	16.8
	Saskatoon	20	20.7	17.8	18.4

Variable	Categories	Unweighted (%)		Weighted[a] (%)	
		Males (*n*=577)	Females (*n*=1,335)	Males (*n*=914)	Females (*n*=998)
	Toronto	16.3	12.4	16.2	15.7
	Kingston	11.5	13.3	9.1	11.2
	Quebec city	23.2	24.1	25	30.8
	Halifax	4.5	3.7	2.8	2.1
Education	Less than high school	23.1	31	16.5	19.2
	High school graduation	12.8	14.4	12.6	14.8
	Trade/professional certification	20.3	21.8	23.5	24.9
	University without degree	7.8	8.3	6.3	9.2
	University with certificate/degree	36	24.5	41.1	31.9

[a]Both unweighted and weighted columns refer to the same sample. By design, CaMos oversampled women and elderly. Therefore, the weighted sample sizes (*n*) in women and men are different than the unweighted sample sizes

Table 2

Normative data for 25(OH)D (nmol/L)—weighted by sex and (10-year) age group to the Canadian census

Sex	Age group (years)	Non-weighted N	Weighted N	Mean (SE) nmol/L	Percentiles (nmol/L)								
					Min (0)	5	10	25	50	75	90	95	Max (100)
Males	35–50	61	401	73.37 (3.11)	12.07	30.1	39.53	56.08	77.09	91.14	104.38	112.45	122.35
	51–70	283	384	66.26 (1.36)	15.67	28.46	33.88	50.68	66.72	79.78	96.17	107.34	136.05
	>70	233	130	71.74 (1.80)	20.98	33.92	40.98	54.03	68.5	86.9	97.86	108.1	209.17
	35+	577	915	70.16 (1.02)	12.07	30.1	36.35	53.52	71.99	85.65	100.3	107.34	209.17
Females	35–50	88	422	71.01 (2.47)	11.24	43.6	44.31	51.48	69.06	85.03	102.25	109.53	135.97
	51–70	681	393	69.74 (0.89)	10	33.21	40.14	53.48	69.56	84.25	95.62	104.66	206.23
	>70	566	182	71.25 (1.08)	11.41	34.14	41.61	55.48	69.79	82.6	99.81	118.24	212.05
	35+	1,335	997	70.55 (0.65)	10	35.7	43.89	53.16	69.06	84.25	100.09	109.53	212.05
	All	1,912	1,912	70.36 (0.55)	10	32.88	40.88	53.18	70.06	85.22	100.09	109.31	212.05

Table 3

25(OH)D Groupings (vitamin D status)—weighted by sex and (10 yr) age group to the Canadian census

Sex	Age group (years)	25(OH)D (nmol/L) groupings												Total	
		<27.5			27.5–49.9			50–74.9			75				
		n	%	SE of %	n	%	SE of %	n	%	SE of %	n	%	SE of %	n^a	%
Males	35–50	16	3.9	2.7	46	11.6	4.2	138	34.5	6.1	201	50	6.5	401	100
	51–70	10	2.5	0.9	86	22.3	4.1	155	40.4	4.5	134	34.9	4.3	384	100
	>70	3	2.6	1.1	24	18.7	2.7	48	36.5	3.2	55	42.2	3.3	130	100
	35+	28	3.1	1.2	156	17.1	2.6	341	37.3	3.3	389	42.6	3.4	915	100
Females	35–50	3	0.7	0.7	90	21.4	4.6	171	40.5	5.7	158	37.5	5.6	422	100
	51–70	8	2.1	0.8	70	17.7	2.1	155	39.3	2.6	161	41	2.7	393	100
	>70	5	2.5	0.7	29	16.0	1.7	76	41.6	2.2	73	39.8	2.2	182	100
	35+	16	1.6	0.4	189	19.0	2.1	401	40.2	2.6	392	39.3	2.6	997	100
	Total	44	2.3	0.6	345	18.1	1.7	742	38.8	2.1	781	40.8	2.1	1912	100

[a]The total number of participants in each age category of vitamin D status may not sum to the total number of participants per age group due to rounding

Table 4

Seasonal variation in 25(OH)D <50 nmol/L vitamin D supplementation

Vitamin D Supplementation (mean daily)	25(OH)D <50nmol/L (%)											
	Winter			**Spring**			**Summer**			**Fall**		
	n	**%**	**SE of %**	**n**	**%**	**SE of %**	**n**	**%**	**SE of %**	**n**	**%**	**SE of %**
0	66	48.2	7.0	83	40.9	6.6	26	9.2	2.4	80	22.2	4.3
400 IU	10	12.6	3.5	48	25.5	6.6	6	4.6	1.7	45	26.8	7.2
>400 IU	3	4.8	1.9	11	10.0	4.3	4	5.0	2.0	7	5.9	4.1

Table 5

Multivariate regression for independent determinants of 25(OH)D (nmol/L)

Correlates	Parameter estimates (95% CI)	
	Females	**Males**
Age group (years)		
71+	−0.78 (−5.66; 4.10)	1.31 (−5.39; 8.01)
51–70	0.96 (−3.77; 5.68)	−1.79 (−8.26; 4.69)
35–50	Reference	Reference
Ethnic background		
Other	−9.08 (−15.14; −3.02)	−15.22 (−22.69; −7.75)
White	Reference	Reference
Body Mass Index (kg/m^0)		
30+	−11.12 (−14.04; −8.21)	−8.17 (−13.49; −2.85)
25–29.9	−5.83 (−8.45; −3.21)	−3.78 (−8.20; 0.64)
<25	Reference	Reference
Season		
Fall	−3.48 (−7.18; 0.22)	−9.62 (−15.19; −4.06)
Winter	−13.51 (−17.44; −9.58)	−17.31 (−23.87; −10.75)
Spring	−6.12 (−9.64; −2.61)	−13.22 (−18.85; −7.60)
Summer	Reference	Reference
Vitamin D supplementation (per 400 IU)	3.71 (2.82; 4.60)	0.47 (−1.74; 2.67)
Vitamin D supplementation (per 400 IU) by season[a]		
Vitamin D by fall	1.84 (0.4; 3.29)	5.27 (2.18; 8.35)
Vitamin D by winter	2.37 (1.02; 3.72)	10.81 (5.37; 16.24)
Vitamin D by spring	0.39 (−0.85; 1.62)	3.66 (1.07; 6.25)
Vitamin D by summer	Reference	Reference
Vitamin D—dietary[b] (per 200 IU)	3.24 (1.27; 5.22)	2.21 (−0.74; 5.17)
Sun exposure		
Never	−8.58 (−14.20; −2.95)	−3.61 (−11.27; 4.04)
Seldom/Regularly	−8.05 (−13.62; −2.48)	2.23 (−5.26; 9.72)
Often	Reference	Reference
Sunscreen use		
Usually/always	−1.33 (−4.05; 1.39)	0.987 (−3.72; 5.45)
Sometimes	0.92 (−2.24; 4.09)	1.07 (−3.78; 5.91)
None	Reference	Reference
Regular activity participation		
No	−2.94 (−5.26; −0.63)	−3.55 (−7.34; 0.23)
Yes	Reference	Reference

[a]Interaction between vitamin D supplementation and season

[b]Vitamin D from fortified milk, soy beverages, and yogurt