Original Article

Overweight and obesity are associated with lower vitamin D status in Canadian children and adolescents

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Abstract

Introduction: There is evidence that 25-hydroxyvitamin D levels are lower in overweight and obese youth. This study examined the relationship between weight status and 25-hydroxyvitamin D, while controlling for confounders, in Canadian youth.

Methods: Plasma 25-hydroxyvitamin D from subjects aged 6 to 17 years from the Canadian Health Measures Survey cycles 1 (2007 to 2009) and 2 (2009 to 2011) was used. Sex-specific multiple linear regression and logistic regressions examined the relationship of overweight and obesity (body mass index $\geq$ 85th percentile) with 25-hydroxyvitamin D levels and the odds of 25-hydroxyvitamin D <40 nmol/L and <50 nmol/L.

Results: The prevalence of risk of vitamin D deficiency (25-hydroxyvitamin D < 30 nmol/L) was 6% (95% confidence interval [CI] 3.26% to 10.12%). Vitamin D inadequacy, estimated by levels <40 nmol/L, was 15% (95% CI 10.34% to 20.39%; 19% [95% CI 13.1 to 25.6] for teenagers). Seventy per cent (95% CI 63.59 to 75.17) had levels >50 nmol/L, consistent with achieving the Recommended Dietary Allowance. In adjusted analyses, overweight/obesity (1/3 of subjects) was independently associated with lower 25-hydroxyvitamin D for both sexes after adjustment for age, race, income, season, vitamin D supplementation and daily milk consumption. For 25-hydroxyvitamin D <40 nmol/L, the overweight/obese odds ratio for males was 2.63 (95% CI 1.34 to 5.18). For 25-hydroxyvitamin D <50 nmol/L, overweight/obese odds ratios were 2.19 (95% CI 1.46 to 3.28) for males and 1.39 (95% CI 1.05 to 1.84) for females.

Conclusions: This study confirms the inverse association between adiposity and serum concentrations of 25-hydroxyvitamin D in Canadian youth and the independent association of overweight/obesity to 25-hydroxyvitamin D level and vitamin D status after adjustment for other factors.

Keywords: 25-Hydroxyvitamin D; Adolescents; Canadian Health Measures Survey; Children; Obesity; Overweight; Vitamin D.

Adequate vitamin D status in childhood and adolescence is necessary to achieve optimal bone growth and peak bone mass (1). Vitamin D is derived from food, supplements and skin exposure to ultraviolet B (UVB) rays from sunlight. Cutaneous synthesis of serum 25-hydroxyvitamin D [25(OH)D] is influenced by skin pigmentation, age,

season, latitude, clothing coverage and sunscreen use (2). Dietary Reference Intakes for vitamin D for youth are based on levels estimated to maximize calcium absorption, positively affect bone mineral content and density and prevent rickets and osteomalacia in normal, healthy populations (1).

Vitamin D status is assessed by the biomarker 25(OH)D as it reflects both dietary (food and supplements) sources and UVB exposure (1). Concentrations <30 nmol/L are associated with risk of deficiency, and levels <40 nmol/L with population inadequacy (1,3). A level of 50 nmol/L is consistent with achievement of the Recommended Dietary Allowance, which covers the needs of 97.5% of the population (1). Between 2007 and 2009, the prevalence of adolescents (12 to 19 years) with 25(OH)D <40 nmol/L, assessed in the Canadian Health Measures Survey (CHMS), was 14% (20% in winter and 11% in summer) (4). These data suggested a concern for vitamin D status in Canadian youth.

There is evidence that 25(OH)D levels are lower in overweight and obese youth (5–8). Lower 25(OH)D may be due to sequestration of 25(OH)D by adipose tissue, volumetric dilution and other mechanisms (9,10). In US youth consuming less than the Estimated Average Requirement for vitamin D (400 IU), the likelihood of 25(OH)D <50 nmol/L was five times higher in the overweight and obese compared with healthy weight counterparts (5). Lower levels of vitamin D have been associated with higher risk of impaired glucose tolerance (7,8) and metabolic syndrome (7,11) among overweight and obese youth. Obesity has been associated with higher prevalence of fracture in children (12,13). Fat-induced hormonal changes to bone accrual have been investigated as causes (12–14).

Childhood obesity is an important clinical and public health issue. In Canada, 19% of youth aged 5 to 17 years are overweight; a further 15% of boys and 11% of girls are obese (15). This study sought to determine if overweight and obesity in Canadian youth are independently associated with 25(OH)D levels.

MATERIALS AND METHODS

Data

This study used cross-sectional data from CHMS cycles 1 (2007 to 2009) and 2 (2009 to 2011) (16,17). CHMS consisted of: (1) a household interview on sociodemographic characteristics and an in-depth health questionnaire and (2) a visit to a mobile examination centre for direct measurements including height and weight, and collection of urine and blood samples. The Health Canada Research Ethics Board approved the survey. There were 1755 male and 1626 female respondents representing 4.15 million Canadian children (6 to 11 years) and teenagers (12 to 17 years). The final response rate, after sampling strategy adjustment, was 56%. Residents of First Nations on-reserve communities, institutions, certain remote regions, and families of full-time members of the Canadian Forces were excluded. The CHMS sample represents 96.3% of the Canadian population aged 6 to 79 years from all regions, between latitude 43°N and 54°N.

25(OH)D analysis

Plasma 25(OH)D levels were measured using the LIAISON 25-Hydroxyvitamin D TOTAL assay (DiaSorin, Ltd). Lower and upper detection limits were 10 nmol/L and 375 nmol/L, respectively. Plasma samples were stored at –80°C. Analyses were performed singly. Within run, coefficients of variation (CVs), measured using control samples, varied from 7.8% to 11.5% and between run, CVs ranged from 8.6% to 10.9%. Overall CVs for cycle 1 were between 8.5% and 10.8% while overall CVs for cycle 2 ranged from 9.4% to 12.9%. The Health Canada laboratory has participated in proficiency vitamin D testing through DEQAS (Vitamin D External Quality Assurance Scheme, UK) since January 2008 and has been in proficient standing since enrollment. Detailed information on the CHMS collection and measurement of plasma 25(OH)D can be found in the *Vitamin D Reference Laboratory Standard Operating Procedures Manual* at www.statcan.gc.ca.

A total of 407 participants were excluded due to missing 25(OH)D values. Values for cycles 1 and 2 were standardized to the NIST and Ghent Reference Method Procedures using equations developed in conjunction with the Vitamin D Standardized Program (18). Values falling below the limit of quantification were assigned a value equal to half the limit of quantification.

Supplement use

To capture the influence of supplement intake on 25(OH)D levels, we focused on supplements reported at the household interview, which was up to 6 weeks prior to the clinic visit. Respondents provided information on medication use within the past month. They provided a Drug Identification Number or Natural Product Number for each medication, where possible, and reported the last time they had taken that medication. We identified products containing vitamin D using Health Canada's Licensed Natural Health Product Database and the Drug Product Database.

Associated factors

Racial background was self-reported from an extensive list and used as a proxy for skin pigmentation. Due to the low number of non-white respondents, racial background was categorized as white and non-white. Seasonality corresponded to the respondents' visit to the mobile examination centre in 'winter' (November to March) or 'summer' (April to October) (4). Income was based on reported total household income adjusted for the number of household members: the lower income households earned <\$30,000 with one to two members, <\$40,000 with three to four members and <\$60,000 with five or more members. Respondents indicated how often they drank milk/enriched milk substitutes or used them on cereal. Responses were categorized as <1/day and ≥1/day.

Figure 1. Mean (95% confidence interval) plasma 25-hydroxyvitamin D (nmol/L) by age and sex in youth measured in the Canadian Health Measures Survey (2007–2011). *Significantly different between males and females of the same age ($P < 0.05$); **Significantly different from 6- to 11-year-olds of the same sex ($P < 0.05$); †Coefficient of variation 16.6–33.3%, interpreted with caution

Figure 2. Mean (95% confidence interval) of plasma 25-hydroxyvitamin D (nmol/L) by body weight classification in youth measured in the Canadian Health Measures Survey (2007–2011). *Significantly different from normal weight subjects ($P < 0.05$); †Coefficient of variation 16.6–33.3%, interpreted with caution; ‡Coefficient of variation >33% for thin group, data suppressed

Body mass index (BMI, kg/m^2) was calculated from measured height and weight. Cut-points for BMI classification were based on the age- and sex-specific method of the World Health Organization for youth (19). BMI was stratified to four percentile categories: thin (<3%), healthy weight (3% to <85%), overweight (85% to <97%) and obese ($\geq 97\%$).

Statistical analysis

Descriptive statistics were used to estimate plasma 25(OH)D concentrations. Multivariate linear regression was used to describe the relationship between concentrations of 25(OH)D and BMI categories and selected covariates. Multivariate logistic regression was used to derive adjusted odds ratios (ORs) for the association between BMI categories and 25(OH)D levels below thresholds. Sex-specific models controlled for age,

income, race, vitamin D supplement use, milk consumption and season. Analyses were conducted in SUDAAN v.10 software (Research Triangle Institute, NC, USA). All estimates were based on data weighted to represent the Canadian population aged 6 to 17 years. Variance estimation (95% confidence interval [CI]) was calculated and t tests tested differences between prevalence and mean estimates. In all analyses, we used bootstrap weights provided with the data and 24 degrees of freedom to account for the sampling design (17). Statistical significance was defined as a P value of < 0.05 .

RESULTS

Sample characteristics and BMI category

The sample consisted of 3381 youths aged 6 to 17 years; 53% were male and 56% were aged 12 to 17 years. Almost three-quarters (73%) were white and 59% were sampled between April and October. Daily milk consumption was common (81%) and a minority (21%) used supplements containing vitamin D. According to BMI classification, 66% were of normal weight, 19% were overweight, 13% were obese (16% of males and 10% of females, $P < 0.05$) and 2% were thin. More vitamin D supplement users were of normal weight compared with non-users. Other selected characteristics (age group, race, income, season of blood collection, milk intake) were similar among BMI categories.

25(OH)D by age and sex

Plasma 25(OH)D concentrations varied with age and sex (Figure 1). Overall, levels were < 30 nmol/L for 6%, < 40 nmol/L for 15% and < 50 nmol/L for 30% for youth 6 to 17 years. Mean levels were lower for male teenagers than male children and for teenagers overall compared to children. Nineteen per cent of teenagers had 25(OH)D levels < 40 nmol/L. In children, mean 25(OH)D levels were lower in females, and the prevalence of levels < 50 nmol/L was higher among females (30%) compared with males (20%).

Association of 25(OH)D with BMI category

Overall, overweight and obese youth had lower 25(OH)D levels (57.4 nmol/L and 54.1 nmol/L, respectively) compared with normal weight youth (61.9 nmol/L; Figure 2). Levels < 40 nmol/L were observed in 27% of those who were obese compared with 12% who were of normal weight and the difference was particularly evident in males (data not shown). Levels < 50 nmol/L were seen in 45% of obese youth versus 26% of those of normal weight. As thinness was rare, further analyses focused on the normal weight, overweight and obese groups.

Factors associated with 25(OH)D

We examined the relationship of selected characteristics and 25(OH)D < 40 nmol/L and < 50 nmol/L stratified by BMI

Table 1. Percentage of children and adolescents having plasma 25(OH)D below indicated cut-offs by BMI categories and selected characteristics

Characteristics	Cut-off (nmol/L)	% of group falling below indicated cut-off (CI)			
		Total	Normal weight	Overweight	Obese
Sex					
Male*	40	13.7 [†] (9.1, 20.1)	10.0 [†] (5.5, 17.8)	12.9 [†] (8.0, 20.2)	29.4 [#] (20.8, 39.9)
	50	28.9 (22.5, 36.3)	23.5 (17.3, 31.2)	32.3 (22.8, 43.5)	46.7 [#] (36.5, 57.2)
Female	40	15.1 (10.5, 21.3)	13.2 [†] (8.3, 20.2)	17.6 [†] (11.5, 25.8)	23.9 [†] (15.1, 35.5)
	50	31.5 (26.2, 37.3)	28.5 (23.1, 34.6)	36.6 (29.2, 44.6)	41.8 [#] (30.6, 53.8)
Age group (years)					
6–11	40	9.7 ^{†,‡} (6.2, 14.9)	8.7 [†] (5.1, 14.3)	11.5 [†] (6.9, 18.7)	NA
	50	25.2 (19.8, 31.6)	22.6 (17.2, 29.1)	30.2 (21.9, 40.0)	30.5 ^{†,‡} (19.4, 44.3)
12–17*	40	18.0 [†] (12.6, 25.1)	13.8 [†] (8.2, 22.3)	18.2 [†] (11.8, 27.1)	39.4 [#] (30.4, 49.1)
	50	34.0 (26.7, 42.0)	28.5 (20.9, 37.6)	37.9 (28.6, 48.1)	56.2 [#] (45.5, 66.5)
Race					
White*	40	8.6 (6.4, 11.4)	6.5 [†] (4.1, 9.9)	7.9 [†] (5.1, 12.1)	20.7 ^{†,‡} (14.4, 28.8)
	50	23.7 (19.3, 28.8)	19.7 (15.2, 25.0)	28.4 [#] (22.0, 35.9)	38.1 [#] (29.1, 48.1)
Non-white	40	29.8 ^{†,‡} (20.1, 41.8)	25.8 ^{†,‡} (16.3, 38.3)	34.5 ^{†,‡} (19.2, 53.7)	42.0 ^{†,‡} (28.2, 57.1)
	50	47.2 [†] (38.1, 56.5)	43.6 [†] (35.5, 52.0)	50.2 [†] (34.8, 65.5)	60.0 ^{†,‡} (45.4, 72.9)
Income					
Lower	40	20.4 (14.3, 28.3)	17.6 [†] (10.9, 27.2)	24.3 ^{†,‡} (15.7, 35.6)	26.7 [†] (13.2, 46.4)
	50	41.6 [‡] (34.5, 49.1)	38.8 [†] (29.7, 48.7)	43.8 (34.2, 54.0)	50.2 (38.4, 61.9)
Higher*	40	12.5 [†] (8.3, 18.4)	9.9 [†] (5.6, 16.8)	12.0 [†] (7.5, 18.5)	27.7 [#] (20.7, 35.8)
	50	26.7 (20.8, 33.5)	22.4 (16.7, 29.4)	31.0 (23.2, 40.1)	43.0 [#] (32.6, 54.0)
Season					
April to	40	10.2 (7.5, 13.8)	7.9 [†] (5.0, 12.3)	11.0 [†] (7.1, 16.7)	20.9 [#] (15.3, 27.8)
October*	50	25.7 (20.7, 31.3)	22.0 (16.6, 28.5)	31.6 (24.3, 40.0)	35.5 [#] (30.3, 41.0)
November to March	40	20.5 ^{†,‡} (13.1, 30.5)	16.9 [†] (9.4, 28.7)	21.5 [†] (12.7, 33.8)	36.5 ^{†,‡,‡} (24.5, 50.5)
	50	36.6 (27.3, 47.1)	31.8 (22.5, 42.8)	38.4 [†] (25.4, 53.4)	58.0 ^{†,‡} (41.7, 72.8)
Vitamin D supplement					
Users	40	4.1 ^{†,‡} (2.2, 7.6)	3.8 ^{†,‡} (2.1, 6.9)	NA	NA
	50	17.1 [†] (12.4, 23.2)	15.9 [†] (11.7, 21.2)	NA	NA
Non-users*	40	17.2 [†] (11.9, 24.1)	13.9 [†] (8.6, 21.8)	18.3 [†] (12.7, 25.5)	30.1 [#] (21.7, 40.0)
	50	33.7 (27.4, 40.6)	29.1 (22.5, 36.6)	39.4 (30.8, 48.8)	46.4 [#] (38.6, 54.4)
>1/day milk consumers					
Yes*	40	12.2 [†] (8.2, 17.7)	10.0 [†] (5.9, 16.5)	13.3 [†] (9.1, 19.0)	21.6 [†] (13.2, 33.2)
	50	27.1 (21.6, 33.3)	23.1 (17.9, 29.3)	32.3 (24.1, 41.6)	39.6 [#] (28.0, 52.5)
No	40	23.5 ^{†,‡} (15.6, 33.8)	18.1 [†] (11.3, 27.6)	22.7 [†] (12.0, 38.8)	49.9 ^{†,‡} (32.8, 67.1)
	50	42.8 [‡] (32.7, 53.5)	38.0 [†] (28.0, 49.1)	42.7 [†] (27.5, 59.4)	65.4 ^{†,‡} (46.0, 80.7)

Household population aged 6–17 years, Canada, 2007–2011; thin subjects excluded; NA: estimate not available due to low sample size or coefficient of variation >33%. BMI Body mass index; CI Confidence interval. *Reference category; [†]Coefficient of variation 16.6–33.3%, interpreted with caution; ^{††}Significantly different from reference category (P<0.05); [#]Significantly different from normal weight category (P<0.05)

category to determine if the prevalence of the lower level varied with increasing adiposity (Table 1). When obese individuals were compared with those of normal weight, the prevalence of 25(OH)D levels <40 nmol/L was significantly higher among the obese in males, teenagers, whites and those of higher

income, tested in winter and summer or not using vitamin D supplements. For example, among whites, 21% of those who were obese had 25(OH)D levels <40 nmol/L compared with 7% who were of normal weight. Among whites, 38% of those who were obese had 25(OH)D levels <50 nmol/L compared

Table 2. Beta coefficients relating levels of 25(OH)D to BMI categories, adjusting for selected characteristics, by sex, household population aged 6–17 years, Canada, 2007–2011

Parameter (reference category)	Males			Females		
	β	SE	P*	β	SE	P
Overweight or obese (normal weight)	(4.91)	1.51	0.003	(3.52)	1.43	0.02
Non-white (white)	(7.82)	1.86	0.0003	(12.08)	2.26	0.00002
Lower income (higher income)	(3.14)	1.32	0.03	(4.74)	1.83	0.02
Time of year: November to March (April to October)	(6.73)	2.87	0.03	(6.91)	2.52	0.01
Vitamin D supplement user (non-user)	6.89	1.89	0.001	3.98	1.82	0.04
Milk non-consumer (milk consumer)	(1.85)	1.69	0.28	(5.49)	1.93	0.009
Age (continuous)	(0.82)	0.22	0.001	(0.14)	0.29	0.623
Overweight or obese and milk non- consumer interaction	(4.70)	4.44	0.30	(4.73)	2.02	0.028

P values <0.05 are considered to be significantly different from reference category. The brackets indicate a negative relationship. BMI Body mass index; SE Standard error

with 20% who were of normal weight; among non-whites, estimates were 60% versus 44%, respectively.

Multiple and logistic regression models

Overweight and obesity were both associated with lower 25(OH)D levels, and to give strength to the analysis, they were grouped as an explanatory variable in the regressions. Overweight/obese males and females had significantly lower levels of vitamin D after adjusting for the independent effects of covariates (Table 2). Other variables independently associated with lower 25(OH)D level were non-white race, winter season, non-use of vitamin D supplements and lower income for both males and females. For males, increasing age was negatively related. For females, there was a strong influence of lack of daily milk consumption, and a significant interaction between BMI group and milk consumption was noted.

ORs for the prevalence of 25(OH)D below thresholds related to Dietary Reference Intakes were calculated using multivariate logistic regression stratified by sex. For 25(OH)D <40 nmol/L, overweight/obesity was independently associated with a significantly higher OR compared with normal weight for males only; the OR was 2.63 (95% CI 1.34 to 5.18). For 25(OH)D <50 nmol/L, overweight/obesity was an independent factor significantly associated with higher ORs in both males and females; ORs were 2.19 (95% CI 1.46 to 3.28) for males and 1.39 (95% CI 1.05 to 1.84) for females.

DISCUSSION

This study confirms the inverse relationship between 25(OH)D levels and estimates of adiposity in youth (5–8) and establishes adiposity as an independent risk factor in a nationally representative population-based sample of Canadian children

and adolescents, similarly to US results (6). As obesity was more prevalent among males than females, we analyzed sexes separately. Obese or overweight boys had over twice the odds of having 25(OH)D levels <40 nmol/L and <50 nmol/L compared with normal weight boys; obese or overweight girls had 1.4 times the odds of levels <50 nmol/L. For girls, there was an interaction with milk such that overweight and obese girls who did not drink milk daily had an additional risk of lower 25(OH)D level.

Overall, 6% in this study had vitamin D levels <30 nmol/L associated with risk of deficiency. Almost twice the proportion of teenagers (19%) compared with children (9.7%) had levels <40 nmol/L, the cut-off for population risk of inadequacy (1,3) supporting the finding that 25(OH)D declines with puberty onset (8). One-third of teenagers and female children had serum levels <50 nmol/L, the goal level for individuals (1).

It is unclear as to whether vitamin D deficiency causes obesity (through mechanisms yet unknown (20)) or vice versa (9). There is some evidence that obese individuals show an attenuated serum 25(OH)D response to vitamin D replacement (9,21) and UVB radiation (9), suggesting a decrease in synthesis.

Body mass affects bone mass. Obesity has been reported as a risk factor for fractures in childhood. A potential mechanism for this is through proinflammatory factors, including leptin, leading to decreased renal synthesis of 1,25-dihydroxyvitamin D (14). Lower vitamin D levels stimulate parathyroid hormone production which reduce bone formation and increase bone resorption (13). Overweight and obese children have more muscle mass than normal weight children. Although lean mass contributes more to their increased bone parameters, the role of fat mass on bone is inconsistent and more longitudinal research is needed (22).

In addition to bone considerations, low vitamin D is associated with insulin resistance and metabolic syndrome (7,8,11). In Canadian youth 12 to 19 years, the prevalence of metabolic syndrome is 3.5% (23). An inverse relationship between vitamin D status and cardiometabolic risk has been reported for adult Canadians (24) but not yet for Canadian youth.

In this study, race was a strong independent factor associated with 25(OH)D. UVB ray absorption relative to skin pigmentation is an important predictor of 25(OH)D status as darker pigmentation requires greater exposure to UVB rays to reach the same amount of vitamin D₃ synthesis as lighter skin (25). Non-white youth with high BMIs are therefore at a greater risk of vitamin D deficiency (6,11). Further, significantly more obese white adolescents than obese black or Hispanic adolescents were able to normalize their serum 25(OH)D levels after a course of vitamin D treatment to correct for insufficiency (21).

Only a minority of youth (21%) reported vitamin D supplementation yet it was an independent factor positively associated with 25(OH)D levels. Others have reported that vitamin D supplementation increases serum 25(OH)D in overweight/obese subjects but less so compared with normal weight subjects (21,26). This suggests that heavier children and adolescents may require higher doses of vitamin D to achieve a repletion of serum 25(OH)D.

The prevalence of daily milk consumption was similar among the BMI categories for males and females. Similarly, obese and non-obese Canadian youth in a clinical population had similar total dietary vitamin D intakes from food, even when stratified by sex (27). Yet, we observed an interaction of overweight/obesity with milk in females only. In Canada, vitamin D-enriched milk is the most important food source of vitamin D (28). Garriguet (29) reported that milk product consumption declines with age among Canadian youth and by age 10 to 16 years, 83% of females and 61% of males were not consuming recommended levels. Our findings suggest an additional negative association with 25(OH)D for females who are overweight or obese.

A strength of the study is its nationally representative and population-based sample containing youth from regions across Canada, measured year-round. Limitations include its cross-sectional nature which precludes concluding cause and effect of overweight/obesity on vitamin D status. CHMS cycles 1 and 2 provide limited information on vitamin D intake from food, have only a proxy for skin pigmentation and do not survey some communities at high risk of vitamin D inadequacy. A potential issue is the reliance on the DiaSorin Liaison TOTAL 25(OH)D method, which has been shown to be affected by changes in vitamin D binding protein concentration (30), which may itself vary in obesity.

CONCLUSIONS

This study corroborates evidence from other countries that overweight and obesity in Canadian youth are independently

associated with vitamin D inadequacy and lower attainment of 25(OH)D concentrations associated with optimal vitamin D intake. This highlights the need to increase awareness of the importance of vitamin D sources from food, e.g., milk or enriched milk substitutes, or supplements in those overweight and obese during this developmental period. Research should further explore the interrelationship between vitamin D status, adiposity and adverse bone and metabolic outcomes and the mechanisms through which these may occur.

Conflict of Interest

None of the authors has a conflict of interest.

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