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Vitamin D and Dental Caries in Children

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Abstract

The purpose of this study was to assess the relationship between vitamin D status and dental caries in Canadian school-aged children participating in the Canadian Health Measures Survey (CHMS). The CHMS was a national cross-sectional study involving physical assessments, laboratory analysis, and interviews. Analysis was restricted to data for 1,017 children 6 to 11 y of age. Outcome variables included the presence of caries and overall total caries score (dmft/DMFT index). Levels of 25-hydroxyvitamin D (25(OH)D) were measured from serum samples obtained from participants. Bivariate analysis, logistic regression for the presence of caries, and multiple linear regression for total caries scores were used. Significance was set at $P \leq 0.05$. Overall, 56.4% of children experienced caries, and the mean dmft/DMFT score was 2.47 (95% CI 2.09 to 2.84). The unadjusted odds of children with 25(OH)D levels ≥75 nmol/L having experienced caries was 0.57 (95% CI 0.39 to 0.82), while the odds for caries at the ≥50 nmol/L level was 0.56 (95% CI 0.39 to 0.89). After controlling for other covariates, backward logistic regression revealed that the presence of caries was significantly associated with 25(OH) levels <75 nmol/L and <50 nmol/L, lower household education, not brushing twice daily, and yearly visits to the dentist. Similarly, multiple linear regression revealed that total dmft/DMFT caries scores were also associated with 25(OH)D concentrations <75 nmol/L, not brushing twice daily, lower household education, and yearly visits to the dentist. Data from a cross-sectional, nationally representative sample of Canadian children suggest that there is an association between caries and lower serum vitamin D. Improving children's vitamin D status may be an additional preventive consideration to lower the risk for caries.

Keywords: child, health survey, dental health surveys, oral health, nutritional status, Canada

Introduction

Vitamin D plays a key role in craniofacial development and the maintenance of good oral health (Berdal et al. 2005). There is a growing body of evidence regarding the association between vitamin D and dental health (Dietrich et al. 2004; Grant 2008; Schroth et al. 2014). Inadequate concentrations of 25-hydroxyvitamin D (25(OH)D) have been linked with periodontal disease, tooth loss, and oral bone loss (Dietrich et al. 2004), and vitamin D supplementation has been shown to improve clinical periodontal outcomes (Krall et al. 2001; Hildebolt 2005). Vitamin D also influences enamel and dentin formation (Berdal et al. 2005). Episodes of malnutrition and vitamin D deficiency during periods of primary and permanent tooth formation can result in enamel hypoplasia and dental caries (Purvis et al. 1973; Alvarez et al. 1993).

Recently, low prenatal 25(OH)D levels have been reported to be associated with early childhood caries (ECC) in infants (Schroth et al. 2014), and children with severe ECC have also been found to have lower 25(OH)D levels than cavity-free children (Schroth et al. 2012; Schroth et al. 2013). Another group has recently stated that pregnant women with higher prenatal intakes of vitamin D were more likely to report that their child was caries-free compared with women who had lower vitamin D intakes (Tanaka et al. 2015).

Much of the initial focus on the role of vitamin D in caries occurred during the 1920s and 1930s through the efforts of Mellanby and colleagues (Mellanby et al. 1924; Mellanby 1928; Mellanby and Pattison 1928). Several historical reports document the beneficial effects of vitamin D supplementation in reducing dental caries in children (Mellanby et al. 1924; Mellanby and Pattison 1926; McBeath 1933; Anderson et al. 1934; Eliot et al. 1934). Evidence arising from these early studies was included in a recent meta-analysis of vitamin D supplementation and caries that concluded (with low certainty) that

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supplementation with vitamin D_2, D_3, and ultraviolet radiation therapy reduced the relative risk for caries (Hujoel 2013).

Vitamin D is obtained from both endogenous sources (i.e., skin synthesis) and exogenous sources (i.e., foods that naturally contain vitamin D, foods fortified with vitamin D, and dietary supplements). Unfortunately, some children and adults do not fulfill current recommended levels for 25(OH)D sufficiency (Vieth et al. 2001; Holick 2007; Langlois et al. 2010). While the Institute of Medicine (IOM) has set the threshold for adequacy at 50 nmol/L, there is a growing consensus that levels at or above the 75 nmol/L cutoff offer considerable benefit and protection against many ailments (Whiting and Calvo 2006; IOM 2011; Vieth 2011).

The purpose of this study was to assess the relationship between serum 25(OH)D status and dental caries in Canadian school-aged children, aged 6 to 11 y, participating in the Canadian Health Measures Survey (CHMS).

Materials and Methods

Data for this study were obtained from children 6 to 11 y of age (the youngest subjects) participating in the CHMS undertaken from 2007 to 2009 (Health Canada 2010). CHMS was a national, cross-sectional survey that was a representative sample of 97% of the Canadian populace aged 6 to 79 y (Health Canada 2010). Data collection involved both direct physical measurements and interviews with participants after informed consent was obtained (Health Canada 2010). As with other Statistics Canada surveys, the CHMS excluded residents of First Nations Reserves or Crown land, residents of institutions, full-time members of the Canadian Forces, and residents of certain remote regions of Canada (Health Canada 2010).

Statistics Canada used a probability sampling approach, incorporating aspects of stratification and cluster sampling (Health Canada 2010). From a potential of 257 identified sites, 15 were selected and stratified by region. There was 1 site in Atlantic Canada, 4 sites in Quebec, 6 in Ontario, 2 in the Prairies, and 2 in British Columbia (Health Canada 2010). Approximately 350 respondents were sampled at each site, stratified by age group (5 age groups: 6 to 11, 12 to 19, 20 to 39, 40 to 59, and 60 to 79 y). For the purposes of this investigation, we restricted our analysis to children aged 6 to 11 y.

Dental examinations were included as part of the clinic visit and were completed by 12 calibrated Canadian Forces dentists trained in survey methodology who traveled in teams of 2 (Health Canada 2010). Individual teeth were examined and their condition recorded. No radiographs were used. Based on the captured clinical data, 2 main outcome variables for caries were created. The first was the presence or absence of dental caries involving both the primary and permanent dentitions. The second was the total count of the number of decayed, missing, or filled teeth in both the primary and permanent dentitions (dmft/DMFT score).

Vitamin D status of CHMS participants was determined by analyzing 25(OH)D concentrations in serum samples collected during the clinical visit. Analysis of 25(OH)D was performed by the Health Canada laboratory using the Liaison 25 OH Vitamin D Total assay (DiaSorin, Ltd., Stillwater, MN, USA) and measured using chemiluminescence (Langlois et al. 2010). 25(OH)D is the primary form of vitamin D in the circulation and is the best indicator of vitamin D status because it is a good measure of total vitamin D received from both endogenous and exogenous sources (Vieth and Carter 2001; Whiting and Calvo 2006; Holick 2007; Vieth 2011). We considered concentrations ≥75 nmol/L to be optimal (Langlois et al. 2010). However, the IOM's proposed cutoff value for adequacy of ≥50 nmol/L was also used in our analysis. To control for other confounders for caries, additional independent variables were also considered. Oral health–related variables included tooth brushing frequency, dental visit history, and water fluoridation status. Community water fluoridation status in the CHMS was reviewed by McLaren and Emery (2012). Socioeconomic variables of interest included highest attained education in the household, household income adequacy (a standard Statistics Canada classification based on income and household size), and the presence of dental insurance. Dietary variables of interest included the frequency of drinking sugary drinks (such as soda, fruit drinks, and sports drinks) and the frequency of drinking milk.

This study was approved by the University of Manitoba's Health Research Ethics Board and Statistics Canada.

Statistical Analysis

Data were accessed and analyzed within the Regional Data Centre (RDC) at the University of Manitoba using SPSS 20 (IBM, Armonk, NY, USA), SAS 9.2 (SAS Institute, Cary, NC, USA), and SUDAAN 10 (Research Triangle Institute, NC, USA). As per RDC restrictions, original sample sizes are suppressed. Bootstrap weights for variance estimation and weighted results are presented. Degrees of freedom were fixed to 11, and Satterthwait-adjusted statistics were used instead of Wald statistics because bootstrapping was required as per Statistics Canada recommendations. Descriptive statistics included frequencies, means with standard error (SE), and 95% confidence intervals (95% CI). Chi-square analysis was used to determine the unadjusted correlation of each independent variable with caries status. Multiple logistic regression models for caries were developed to determine the adjusted association between 25(OH)D levels and caries status, controlling for potential confounders. Multiple linear regression models for total caries experience (dmft/DMFT score) were also fit. A P value ≤ 0.05 was considered statistically significant.

Results

A total of 1,081 children 6 to 11 y of age participated in the CHMS. For our study, 1,017 children were included because they had both questionnaire and clinical data available; 51.0% were male (95% CI 50.5 to 51.4). To validate our coding methods, we calculated the caries experience and 25(OH)D status in our sample of 6- to 11-y-olds to see how values compared with

Table 1. Associations with Overall Caries Experience in 6- to 11-Year-Olds.

Variable	Proportion with Caries (95% CI)	Proportion Caries-Free (95% CI)	*P* Value	Unadjusted Odds Ratio (95% CI)
Study sample	56.4 (51.7–61.1)	43.6 (38.9–48.3)		
25(OH)D status[a]				
Low (<75 nmol/L)	56.4 (48.5–64.0)	42.4 (34.1–51.1)	0.008	0.57 (0.39–0.82)
Optimal (≥75 nmol/L)	43.6 (36.1–51.5)	57.6 (48.9–65.9)		
25(OH)D status—Institute of Medicine threshold[a]				
Low (<50 nmol/L)	68.5 (62.8–73.8)	31.5 (26.2–37.2)	0.0015	0.56 (0.39–0.80)
Optimal (≥50 nmol/L)	54.8 (48.3–61.3)	45.2 (38.7–51.8)		
Dental insurance[a]				
Yes	80.2 (73.8–85.3)	77.2 (67.9–84.4)	0.54	1.20 (0.64–2.22)
No	19.8 (14.7–26.1)	22.8 (15.6–32.1)		
Visits the dentist at least once a year[a]				
Yes	94.0 (88.6–96.9)	90.0 (84.5–93.6)	0.02	1.75 (0.99–3.10)
No	6.0 (3.1–11.4)	10.0 (6.4–15.5)		
Household education[a]				
High school	23.1 (17.1–30.5)	11.8 (9.0–15.3)	0.01	
Certificate or diploma	45.9 (38.8–53.2)	40.6 (33.2–48.6)		0.58 (0.40–0.84)
Bachelor's degree	21.5 (14.7–30.2)	32.5 (29.0–36.1)		0.34 (0.18–0.64)
Degree beyond bachelor's	9.5 (5.8–15.2)	15.1 (9.1–23.9)		0.32 (0.19–0.55)
Water fluoridation[a]				
Yes	37.3 (22.2–55.2)	45.1 (23.8–68.4)	0.22	0.72 (0.42–1.26)
No	62.7 (44.8–77.8)	54.9 (31.7–76.2)		
Household income adequacy[a]				
>$60,000 (high)	8.1 (5.6–11.5)	4.6 (2.4–8.8)	0.24	0.63 (0.26–1.56)
>$20,000 to <$60,000 (middle)	36.1 (29.0–43.9)	32.4 (25.6–40.0)		0.50 (0.18–1.38)
≤$20,000 (low)	55.8 (47.3–65.1)	63.0 (54.0–71.2)		
Drink milk 1/day[a]				
Yes	90.5 (87.0–93.2)	88.8 (85.1–91.7)	0.46	1.20 (0.71–2.04)
No	9.5 (6.8–13.0)	11.2 (8.3–14.9)		
Drink sugary drinks 1/day[a]				
Yes	64.0 (59.2–68.5)	62.4 (58.5–66.2)	0.66	1.07 (0.77–1.49)
No	36.0 (31.5–40.8)	37.6 (33.8–41.5)		
Brush 2 times/day[a]				
Yes	70.9 (65.7–75.7)	80.6 (76.0–84.5)	0.0049	0.59 (0.42–0.83)
No	29.1 (24.3–34.3)	19.4 (15.5–24.0)		

[a]Chi-square analysis.

those presented in the CHMS oral health report (Health Canada 2010). Overall, 56.4% of our sample experienced caries compared with 56.8% presented in the CHMS report. The mean dmft, DMFT, and total dmft/DMFT scores also matched those presented in the CHMS oral health report. On average, children had 2 primary teeth affected by caries (dmft = 1.97, 95% CI 1.71 to 2.24) and 0.49 permanent teeth affected by caries (95% CI 0.34 to 0.64), for a total dmft/DMFT score of 2.47 (95% CI 2.09 to 2.84). The majority of children (87.5%) met the IOM's threshold for 25(OH)D adequacy (≥50 nmol/L) (Committee to Review Dietary Reference Intakes for Vitamin D and Calcium 2011) and 49.7% had optimal concentrations (≥75 nmol/L).

Chi-square analysis was performed to determine the relationship between caries and covariates of interest (Table 1). Unadjusted odds ratios (OR) for caries were also calculated. Children with 25(OH)D concentrations ≥75 nmol/L had significantly lower odds for caries (OR = 0.57, 95% CI 0.39 to 0.82). Similarly, children with levels ≥50 nmol/L had lower odds for caries (OR = 0.56, 95% CI 0.39 to 0.80). A trend was identified between household education levels and caries, with children from homes with higher education levels being at significantly lower odds of having experienced decay. Likewise, children who brushed twice daily had significantly lower odds of having ever experienced caries (OR = 0.59, 95% CI 0.42 to 0.83).

Correlation analysis revealed an inverse relationship between predicted caries score and 25(OH)D level (Appendix Figure). Children with higher 25(OH)D levels had lower caries scores (unadjusted correlation, beta = –0.02, $P = 0.05$).

Logistic regression models for caries were undertaken including all selected covariates of interest (Table 2). Model A (using the 75 nmol/L cutoff for 25(OH)D status) revealed that only brushing twice a day was associated with a significantly lower risk for caries (OR = 0.51, 95% CI 0.33 to 0.79). Meanwhile the full logistic regression model using the IOM cutoff for 25(OH)D status (Table 2, Model B) revealed that 25(OH)D levels ≥50 nmol/L were significantly and independently associated with lower adjusted odds for caries (OR = 0.46, 95% CI 0.26 to 0.83), while brushing twice daily was also associated with a decreased risk for caries.

Table 2. Logistic Regression for Caries Experience in 6- to 11-Year-Olds: Full Model Including All Variables.

	Model A 75 nmol/L Threshold		Model B 50 nmol/L Threshold	
Variable	Adjusted Odds Ratio (95% CI)	*P* Value	Adjusted Odds Ratio (95% CI)	*P* Value
25(OH)D status (reference = low)	0.68 (0.40–1.14)	0.13	0.46 (0.26–0.83)	0.009
Brush 2 times/day (reference = no)	0.51 (0.33–0.79)	0.006	0.51 (0.34–0.75)	0.001
Visits the dentist at least once a year (reference = no)	1.90 (0.82–4.41)	0.12	1.89 (0.88–4.17)	0.10
Drink sugary drinks 1/day (reference = no)	1.09 (0.78–1.54)	0.58	1.14 (0.83–1.54)	0.42
Drink milk 1/day (reference = no)	1.01 (0.58–1.75)	0.98	0.98 (0.58–1.64)	0.94
Water fluoridation (reference = no)	0.63 (0.33–1.20)	0.15	0.66 (0.36–1.19)	0.16
Household education				
Certificate or diploma vs. high school	0.72 (0.38–1.34)	0.31	0.73 (0.41–1.32)	0.31
Bachelor's degree vs. high school	0.54 (0.22–1.33)	0.18	0.53 (0.23–1.20)	0.13
Degree beyond bachelor's vs. high school	0.43 (0.20–0.94)	0.03	0.46 (0.21–0.98)	0.04
Household income adequacy				
High vs. low	1.01 (0.31–3.24)	0.99	1.09 (0.37–3.18)	0.88
Middle vs. low	0.85 (0.23–3.11)	0.82	0.89 (0.29–2.73)	0.84
Dental insurance (reference = no)	1.05 (0.42–2.64)	0.91	1.06 (0.45–2.50)	0.88

Model A used a 25(OH)D threshold of 75 nmol/L. Model B used a 25(OH)D threshold of 50 nmol/L.

Backward elimination was also undertaken to identify those independent variables most associated with the presence of caries (Table 3). The final iteration from the backward elimination process for Model A (using the 75 nmol/L threshold) revealed that concentrations of 25(OH)D ≥75 nmol/L were significantly and independently associated with lower adjusted odds for caries. Similarly, higher levels of household education and brushing twice daily were significantly associated with lower caries risk. Backward elimination for Model B (50 nmol/L threshold) indicated that 25(OH)D levels ≥50 nmol/L, brushing twice daily, and higher levels of household education were associated with lower adjusted odds for caries, whereas, surprisingly, yearly visits to the dentist were associated with increased risk.

Similarly, multiple linear regression analysis for dmft/DMFT caries score was performed and included all covariates of interest (Table 4). Results from the first iteration of Model C (using the 75 nmol/L threshold) revealed that visiting the dentist at least once a year was associated with higher dmft/DMFT scores, while brushing twice daily was associated with significantly lower caries scores. Higher household education levels were also significantly associated with lower caries scores. Following a process of backward elimination (Table 5, Model C), the final model for overall caries score revealed that 25(OH)D concentrations ≥75 nmol/L were significantly and independently associated with lower dmft/DMFT scores. Likewise, higher household education levels and brushing 2 times daily were associated with lower caries scores. Meanwhile, 1 or more visits to the dentist each year were associated with higher dmft/DMFT scores. However, findings from the full multiple linear regression model using the IOM cutoff for 25(OH)D (Table 4, Model D) and the backward elimination model (Table 5, Model D) did not reveal a significant association between 25(OH) levels of ≥50 nmol/L and lower caries scores.

Discussion

To our knowledge, this study involves the largest cross-sectional sample of children used to explore the association between caries and actual serum 25(OH)D status. Our findings suggest that optimal vitamin D concentrations (≥75 nmol/L) are associated with a 39% lower odds for dental caries and overall caries experienced in young school-aged children. This appears to corroborate conclusions from a recent review suggesting that optimal 25(OH)D concentrations (e.g., ≥75 nmol/L) are protective against caries (Grant 2011). Our study also suggests that children meeting and exceeding the IOM threshold for vitamin D adequacy (≥50 nmol/L) are at 47% lower odds for dental caries. Kühnisch et al. (2015) recently reported that higher levels of 25(OH)D were associated with less decay in permanent teeth. Coincidentally, the mean 25(OH)D level for 10-y-old children in that study was the same as in our cohort of 6- to 11-y-olds (75.8 nmol/L vs. 75 nmol/L) (Kühnisch et al. 2015). The belief is that improved vitamin D status can reduce the risk of caries through the induction of defensins and cathelicidin, which have antimicrobial properties (Hewison 2010; Grant 2011). Data from 2 recent case-control studies on the relationship between severe ECC and 25(OH)D status also support the conclusions reached in our current study, that lower 25(OH)D levels are associated with increased caries experience in preschool children (Schroth et al. 2012; Schroth et al. 2013).

A 2012 published systematic review and meta-analysis examining 24 historical clinical trials involving supplementing children and youth with vitamin D_3, vitamin D_2, and ultraviolet light demonstrated that supplementation lowers the risk for caries (Hujoel 2013). The overall finding was that overall vitamin D supplementation resulted in a 47% reduced risk for caries (Hujoel 2013). Marshall and colleagues (2003) also identified that lower vitamin D intake at 3 y of age was significantly

Table 3. Results of Backward Elimination of Logistic Regression for Caries Experience in 6- to 11-Year-Olds.

	Model A 75 nmol/L Threshold		Model B 50 nmol/L Threshold	
Variable	Adjusted Odds Ratio (95% CI)	*P* Value	Adjusted Odds Ratio (95% CI)	*P* Value
25(OH)D status (reference = low)	0.61 (0.46–0.79)	0.002	0.53 (0.34–0.84)	0.007
Brush 2 times/day (reference = no)	0.58 (0.36–0.92)	0.03	0.54 (0.35–0.84)	0.006
Visits the dentist at least once a year (reference = no)	2.04 (1.06–3.92)	0.04	2.00 (1.08–3.70)	0.03
Household education				
Certificate or diploma vs. high school	0.61 (0.36–1.01)	0.06	0.14 (0.40–0.98)	0.04
Bachelor's degree vs. high school	0.43 (0.17–1.09)	0.08	0.17 (0.18–0.94)	0.04
Degree beyond bachelor's vs. high school	0.32 (0.15–0.71)	0.004	0.13 (0.17–0.71)	0.004

Model A used a 25(OH)D threshold of 75 nmol/L. Model B used a 25(OH)D threshold of 50 nmol/L. Backward elimination sequence removed variables in the following order for Model A: drink milk, dental insurance, household income adequacy, drink sugary drinks, water fluoridation. Backward elimination sequence removed variables in the following order for Model B: drink milk, dental insurance, household income adequacy, water fluoridation, drink sugary drinks.

Table 4. Multiple Linear Regression for dmft/DMFT score in 6- to 11-Year-Olds: Full Model Including All Variables.

	Model C 75 nmol/L Threshold (R^2 = 10.1%)			Model D 50 nmol/L Threshold (R^2 = 7.93%)		
Variable	Regression Coefficient	Standard Error	*P* Value	Regression Coefficient	Standard Error	*P* Value
Intercept	3.67	0.89		2.83	0.59	
25(OH)D status (reference = low)	–0.68	0.34	0.07	–0.92	0.58	0.11
Brush 2 times/day (reference = no)	–0.80	0.30	0.02	–0.73	0.31	0.02
Visits the dentist at least once a year (reference = no)	1.30	0.49	0.02	1.11	0.41	0.007
Drink sugary drinks 1/day (reference = no)	0.26	0.20	0.21	0.44	0.25	0.07
Drink milk 1/day (reference = no)	–0.60	0.32	0.09	–0.58	0.35	0.11
Water fluoridation (reference = no)	–0.63	0.37	0.11	–0.54	0.33	0.11
Household education						
Certificate or diploma vs. high school	–0.71	0.55	0.22	–0.40	0.37	0.28
Bachelor's degree vs. high school	–1.64	0.55	0.01	–1.36	0.40	0.001
Degree beyond bachelor's vs. high school	–1.26	0.49	0.03	–0.85	0.57	0.14
Household income adequacy						
High vs. low	0.30	0.51	0.56	0.53	0.57	0.36
Middle vs. low	0.43	0.70	0.55	0.51	0.70	0.46
Dental insurance (reference = no)	–0.52	0.57	0.38	–0.30	0.46	0.11

Model C used a 25(OH)D threshold of 75 nmol/L. Model D used a 25(OH)D threshold of 50 nmol/L.

associated with increased caries in the primary dentition among children participating in the longitudinal Iowa Fluoride Study cohort. The relationship was very strong, as inadequate intake of vitamin D was associated with increased caries experience on logistic regression (Marshall et al. 2003). In addition to these trials, more recent evidence suggests that low prenatal 25(OH)D concentrations increase the risk for ECC in offspring (Schroth et al. 2014). Given this body of evidence, vitamin D supplementation could prove useful in preventing caries in children. Unfortunately, much of the historical evidence has been overlooked by the dental profession (Hujoel 2013; Schroth et al. 2014).

Other covariates that appeared to be associated with caries in this population included household education, brushing frequency, and visits to the dentist. Decay in children and adolescents is generally inversely associated with parents' highest educational attainment (Health Canada 2010). Parental education naturally influences socioeconomic status, which is a well-recognized social determinant of children's oral health (Fisher-Owens et al. 2007). In fact, there is increasing realization that socioeconomic status may be the most significant factor for oral health inequities, placing individuals at risk for caries (Watt 2007). Regular oral hygiene practices like tooth brushing and flossing minimize the risk for decay by controlling plaque levels but may have limited benefit among those with limited access to care and facing significant economic challenges (Fisher-Owens et al. 2007; Canadian Academy of Health Sciences 2014).

The observation that more frequent visits to the dentists were associated with higher dmft/DMFT scores was somewhat surprising. It could be that parents sought dental care because their child had obvious caries. It is also possible that children who experienced caries and underwent restorative treatment to deal with past tooth decay were more likely to visit the dentist on a more frequent basis to prevent further disease. Another theory is that the overall dmft/DMFT might be influenced by a

Table 5. Results of Backward Elimination of Multiple Linear Regression for dmft/DMFT Score in 6- to 11-Year-Olds.

	Model C 75 nmol/L Threshold (R^2 = 9.4%)			Model D 50 nmol/L Threshold (R^2 = 7.7%)		
Variable	Regression Coefficient	Standard Error	*P* Value	Regression Coefficient	Standard Error	*P* Value
Intercept	2.90	0.57		3.94	0.57	
25(OH)D status (reference = low)	–0.91	0.28	0.008	–0.80	0.42	0.06
Brush 2 times/day (reference = no)	–0.83	0.40	0.06	–0.89	0.41	0.03
Visits the dentist at least once a year (reference = no)	1.64	0.30	0.0002	1.52	0.33	0.0001
Drink sugary drinks 1/day (reference = no)				0.60	0.24	0.01
Household education						
Certificate or diploma vs. high school	–0.68	0.46	0.17	–0.47	0.27	0.08
Bachelor's degree vs. high school	–1.69	0.46	0.004	–1.53	0.38	0.0001
Degree beyond bachelor's vs. high school	–1.39	0.52	0.02	–1.04	0.55	0.06

Model C used a 25(OH)D threshold of 75 nmol/L. Model D used a 25(OH)D threshold of 50 nmol/L. Backward elimination sequence removed variables in the following order for Model C: dental insurance, household income adequacy, water fluoridation, drink milk, drink sugary drinks. Backward elimination sequence removed variables in the following order for Model D: dental insurance, household income adequacy, water fluoridation, drink milk.

"treatment effect," whereby the more frequently one visits the dentist, the more likely one is to receive treatment.

Strengths of this study include the large sample size, the representative nature of the sample under investigation, and the fact that dental examinations were performed by trained and calibrated dentists. Another advantage was that we examined actual patient serum 25(OH)D levels, which is the recognized gold standard in determining an individual's overall vitamin D status (as it accounts for both dietary and endogenous synthesis), instead of relying on dietary intake estimates (Langlois et al. 2010). We were also able to control for several factors recognized to contribute to caries risk. A limitation of this study is the cross-sectional nature of data captured in the CHMS, which does not allow us to determine causality. Further, this type of study design does not provide us with any prior knowledge of children's vitamin D status at the time their teeth were developing (Kühnisch et al. 2015). Although there is a lack of information on whether and how levels of 25(OH)D change in children as they age, there is some cross-sectional evidence to imply that average concentrations reported in young infants and toddlers are similar (Lichtenstein et al. 1986) and may not dramatically differ from those in school-aged children (Houghton et al. 2010; El Hayek et al. 2013). However, other reports suggest that there may be a downward trend in 25(OH)D concentrations with increasing age during childhood (Kumar et al. 2009; El Hayek et al. 2013). Knowing that vitamin D levels may not change dramatically during childhood, one could argue that those children with adequate and optimal levels of 25(OH)D in this study likely had beneficial concentrations in the past, during previous periods of permanent tooth development, thereby ensuring proper development of enamel and dentin that would be more resistant to caries.

Another potential limitation included the absence of the season when 25(OH)D serum samples were collected from participants as a covariate in our modeling. However, a report on the vitamin D status of participants in the CHMS reported no statistically significant seasonal differences among 6- to 11-y-olds (76.1 nmol/L April to October vs. 73.0 nmol/L November to March) (Langlois et al. 2010). Since all children in our sample were between the ages of 6 and 11 y, age was not included as a variable in our analysis. While this may be a limitation, it reflects the practice of other investigators who have analyzed dental data from the CHMS (McLaren and Emery 2012). Our use of 75 nmol/L as our primary cutoff for optimal vitamin D status may be seen as a limitation by some, even though it was a logical approach since the mean 25(OH)D concentration for 6- to 11-y-olds in the CHMS was 75 nmol/L (95% CI 70.3 to 79.7) and 51.4% of children in our cohort had concentrations below this threshold (Langlois et al. 2010). Fortunately, we also undertook analysis using the IOM's threshold of 50 nmol/L, even though only 14% of 6- to 11-y-olds had concentrations below this mark (Langlois et al. 2010).

Data from a cross-sectional, nationally representative sample of Canadian children suggest that there is an association between dental caries and lower vitamin D. Children with 25(OH)D concentrations ≥75 nmol/L had a 39% lower odds of having experienced caries, while children with levels ≥50 nmol/L had a 47% lower odds for caries. Improving children's vitamin D status may be an additional preventive consideration to lower the risk for caries. Recommending regular vitamin D supplementation during childhood may decrease the overall burden of tooth decay in children.

Author Contributions

R.J. Schroth, contributed to conception, design, data acquisition, analysis, and interpretation, drafted and critically revised the manuscript; R. Rabbani, contributed to design, data acquisition, analysis, and interpretation, drafted and critically revised the manuscript; G. Loewen, contributed to design and data analysis, drafted the manuscript; M.E. Moffatt, contributed to conception, design, data analysis, and interpretation, critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work.

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