Drinking Water Fluoridation and Oral Health Inequities in Canadian Children

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ABSTRACT

Objectives: One argument made in favour of drinking water fluoridation is that it is equitable in its impact on oral health. We examined the association between exposure to fluoridation and oral health inequities among Canadian children.

Participants, setting and intervention: We analyzed data from 1,017 children aged 6-11 from Cycle 1 of the Canadian Health Measures Survey, a cross-sectional, nationally representative survey that included a clinic oral health examination and a household interview. The outcome measure was a count of the number of decayed, missing (because of caries or periodontal disease) or filled teeth, either deciduous or permanent (dmftDMFT). Data were analyzed using linear (ordinary least squares) and multinomial logistic regression; we also computed the concentration index for education-related inequity in oral health. Water fluoridation status (the intervention) was assigned on the basis of the site location of data collection.

Outcomes: Fluoridation was associated with better oral health (fewer dmftDMFT), adjusting for socio-economic and behavioural variables, and the effect was particularly strong for more severe oral health problems (three or more dmftDMFT). The effect of fluoridation on dmftDMFT was observed across income and education categories but appeared especially pronounced in lower education and higher income adequacy households. dmftDMFT were found to be disproportionately concentrated in lower-education households, though this did not vary by fluoridation status.

Conclusions: The robust main effect of fluoridation on dmftDMFT and the beneficial effect across socio-economic groups support fluoridation as a beneficial and justifiable population health intervention. Fluoridation was equitable in the sense that its benefits were particularly apparent in those groups with the poorest oral health profiles, though the nature of the findings prompts consideration of the values underlying the judgement of health equity.

Key words: Canada; fluoridation; oral health; socio-economic factors

La traduction du résumé se trouve à la fin de l'article.

Can J Public Health 2012;103(Suppl. 1):S49-S56.

Drinking water fluoridation is a quintessential example of a population health intervention, i.e., a program or policy operating within or outside the health sector that targets a whole population without regard to variation in individual risk status, and that has the potential to affect health at the population level.[1-3] Since its initial implementation in 1945, drinking water fluoridation has been credited with making significant improvements to population oral health, particularly among children, for whom fluoride has both a pre-eruptive systemic effect and a post-eruptive topical effect in preventing tooth decay.[4-6]

In contrast to the earliest fluoridation experiments, subsequent evidence of effectiveness has been more equivocal.[6,7] A main reason for this trend is the availability of other forms of fluoride, such as the "spectacular increase in the use of fluoride toothpaste" starting in the 1970s,[8] availability of topical fluoride treatment at the dentist or through school/community programs, and fluoride consumed through food prepared or manufactured in fluoridated regions – all of which have made it difficult to isolate exposure to fluoride from drinking water and attribute benefits to that source. There has also been an increase in awareness of the importance of oral health and improved oral hygiene during the past half-century.[9] Despite these trends, available evidence from Canada and elsewhere, on balance, continues to support the effectiveness of drinking water fluoridation for the prevention of tooth decay in populations.[6,7]

Against the backdrop of the changing evidence base, one of the main arguments made by proponents of water fluoridation is that it is equitable: because of its population-wide and structural nature, fluoridation helps everyone, perhaps particularly those who may lack the means or opportunity to visit the dentist regularly or practise good oral health habits.[3,9] Social inequities in health (including oral health) are a prominent concern for population and public health in Canada and worldwide.[10,11] Whereas social inequalities in health refer to differences in health among social groups, inequities in health refer to differences in health that are unfair and avoidable.[10,12,13] Social inequities in health can occur along various axes, such as socio-economic position, gender, race/ethnicity and geographic area; our focus in this study is socio-economic inequities in health, i.e., inequities along social and economic dimensions such as income and educational attainment.

Data from other countries, including Britain,[7] Australia[14] and New Zealand,[15] suggest that fluoridation of drinking water is associated with reduced socio-economic inequities in oral health. For example, a social gradient in oral health (the linear increase in 12-year-old children's scores on decayed, missing, and filled decid-

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Acknowledgements: L. McLaren is supported by a Population Health Investigator Award from Alberta Innovates – Health Solutions. J.C.H. Emery is the Svare Professor in Health Economics at the University of Calgary.

Conflict of Interest: None to declare.

uous teeth with increasing geographic deprivation based on the ward Townsend Score) is much steeper in non-fluoridated Liverpool, UK, than in Newcastle, where drinking water has been fluoridated since the 1960s.[16] To our knowledge, the association between drinking water fluoridation and oral health inequities in the Canadian population is not known.

Available Canadian data indicate dramatic improvements in oral health during recent decades.[17] However, problems remain. Of children aged 6-11 years in the Canadian Health Measures Survey (CHMS) 2007-2009, nearly 57% were affected by dental caries.[17] Further, socio-economic inequities in oral health outcomes exist: caries prevalence and severity were higher (worse) among children from families with lower parental education and without private dental insurance.[17] In Canada, dental services are not part of the national health system; rather, they are financed primarily through private insurance (including employment coverage) and out-of-pocket spending,[18] a fact that arguably increases the importance of population/public health measures such as drinking water fluoridation. Fluoridation has been implemented differentially across Canadian municipalities at the decision of local government.[6] In a 2007 report, it was estimated that 45.1% of the Canadian population received fluoridated drinking water, but this varied provincially from a low of 1.5% in Newfoundland and Labrador to a high of 75.9% in Ontario.[9]

Our objective was to examine the association between exposure to drinking water fluoridation and oral health inequities among Canadian children. As with some other population/public health interventions, drinking water fluoridation is controversial, with proponents and opponents disagreeing over whether this government intervention is justified, given that it restricts individual choice.[19] Highly polarized debate has led to decisions in many Canadian communities (by plebiscite and/or local council vote) to discontinue the practice.[6] With the recent availability of national oral health data from the CHMS, there is both opportunity and impetus to examine this important population/public health question.

PARTICIPANTS, SETTING AND INTERVENTION

Data source and variables

The data source is Cycle 1 of the CHMS, details of which are available at www.statcan.gc.ca. Briefly, the CHMS is a national, cross-sectional survey undertaken during 2007-2009. Data were collected through household interview as well as direct physical measurements within mobile examination clinics. The target population was individuals aged 6-79 years living in privately occupied dwellings across all provinces and territories. Target population exclusions, similar to other Statistics Canada surveys, were "persons living on Indian Reserves or Crown lands, residents of institutions, full-time members of the Canadian Forces and residents of certain remote regions", such that approximately 97% of the Canadian population was represented. A probability sampling strategy was used, incorporating aspects of stratification and cluster sampling. Specifically, a list of 257 potential data collection sites was created, based on Statistics Canada's Labour Force Survey area frame. From the 257 sites, 15 were selected, stratified by region, proportional to the Canadian population: Atlantic (one site), Quebec (four sites), Ontario (six sites), Prairies (two sites) and British Columbia (two sites). Within each site, approximately 350 respondents were sampled, stratified by age group (five age groups: 6-11, 12-19, 20-39, 40-59, 60-79). Of individuals selected for the survey, the response rate for the household interview was 88.3%, of whom 84.9% further agreed to undergo the clinic examination. We focused on children aged 6 to 11 years old.

The clinic visit included a 20-minute oral health examination by a Canadian Forces dentist, during which each tooth was examined and its condition recorded using one of 20 possible codes (the number of potentially applicable codes varied by tooth). On the basis of this information, we created our outcome variable: a count of the number of decayed, missing (because of caries or periodontal disease) or filled teeth, either deciduous or permanent (dmftDMFT). This is a commonly used index of oral health status for the middle-childhood age period.[17,20]

Other variables came from data collected during the household interview. Socio-economic variables were: household education (highest attained education in the household, four categories: high school graduate; certificate or diploma; Bachelor's degree; degree beyond Bachelor's degree); household income adequacy (a standard Statistics Canada classification based on income and household size, three categories: high, middle and low); dental insurance (yes [private or public]/no); and home ownership (versus rent) (yes/no). Oral health variables were tooth brushing (at least twice/day; yes/no), flossing (at least five times/week; yes/no), dental visits (visited the dentist once or more in the past year for treatment or prevention; yes/no); and sugary drink consumption (consumed sugary beverage – such as pop, fruit drink, sports drink – once/day or more during past year; yes/no).

Exposure to drinking water fluoridation

As noted, CHMS respondents were selected from 15 data collection sites across five provinces. According to information from various sources,[6] we classified each site as fluoridated, not fluoridated or mixed. This classification was not always straightforward, but because study conclusions hinge on this classification, we have outlined our rationale in Table 1. Although sampling occurred within a 50 km (urban) or 100 km (rural) radius of the clinic site, the majority of respondents were concentrated close to the site (www.statcan.gc.ca), which increased our confidence in our classification of individuals based on site. Ultimately, we combined the non-fluoridated and the mixed sites, for two reasons: a) with few exceptions (e.g., Vancouver), the sites classified as non-fluoridated were often located geographically close to fluoridated regions, making truly non-fluoridated status unlikely, and b) the small sample in the two sites classified as mixed presented potential data disclosure and reliability issues. We thus ended up with two categories: fluoridated (Moncton NB, Quebec City QC, Toronto ON, Toronto East ON, Edmonton AB and Red Deer AB), and non- or mixed-fluoridation status (Montreal Centre-Ville QC, Montreal Rive-Sud QC, Mauricie QC (Shawinigan), Clarington ON, Northumberland County ON (Cobourg), St. Catharines ON, Vancouver BC, Kitchener-Waterloo ON and Williams Lake-Quesnel BC). By way of further improving the exposure variable, we considered two additional variables: whether the respondents reported usually drinking tap water (yes/no) and whether they had lived in their current home for at least 2 years (yes/no).

Table 1. Rationale for Classification of Fluoridation Status for Each Data Collection Site in the Canadian Health Measures Survey

Site*	Fluoridation Status	Rationale
Moncton, NB	Fluoridated	Moncton began fluoridating its drinking water on September 20, 1970, making it the first municipality in New Brunswick to voluntarily add fluoride to its drinking water ("voluntarily", because communities drawing their water from military bases also drink fluoridated water, due to a 1968 order from the federal defense department that all bases adopt the treatment).[21]
Quebec City, QC	Fluoridated	Quebec City began fluoridating its drinking water in 1978.[22] Although the city voted to discontinue fluoridation in 2008,[9] it is classified as fluoridated based on its lengthy history of fluoridation and its fluoridated status at the time of CHMS data collection (which began in 2007).
Toronto, ON (York University)	Fluoridated	The drinking water of Metropolitan Toronto has been fluoridated since 1963.[23] The administrative region of Metropolitan Toronto was created in 1953 and included the City of Toronto, Etobicoke, North York, Scarborough, and other small municipalities, including Forest Hill.[24] The Toronto site location falls just within the north boundary of North York.
Toronto East, ON (Exhibition Place)	Fluoridated	The drinking water of Metropolitan Toronto has been fluoridated since 1963.[23] The administrative region of Metropolitan Toronto was created in 1953 and included the City of Toronto, Etobicoke, North York, Scarborough, and other small municipalities, including Forest Hill.[24] The Toronto East site location is within the City of Toronto.
Edmonton, AB	Fluoridated	Edmonton has fluoridated its water since 1967.[9]
Red Deer, AB	Fluoridated	Red Deer has fluoridated its water since 1957.[25]
Montreal Centre-Ville, QC	Not fluoridated	Along with Vancouver, Montreal is noteworthy for being one of the large Canadian cities that has never fluoridated its water.[26] The Montreal Centre-Ville site location is in the eastern portion of the island of Montreal / Montreal provincial administrative region, and is therefore classified as non-fluoridated. We acknowledge that some communities within the provincial administrative region of Montreal have in the past fluoridated their water or do so currently, however these appear to be limited to the western portion of Montreal. For example, Dorval has fluoridated its drinking water since 1957 aside from a 5-year hiatus.[9,27] Pointe-Claire began fluoridating its water in 1955,[28] and Pointe-Claire's water filtration plant serves other Montreal communities, including Beaconsfield, Kirkland, and Baie-d'Urfé, in addition to parts of Sainte-Anne-de-Bellevue and Dollard-des-Ormeaux (http://www.h2opointe-claire.qc.ca/index_en.php (accessed June 4, 2012). Pierrefonds began fluoridating its water in 1978; the treated water also serves Dollard-des-Ormeaux, Roxboro, Ste-Genevieve, and Ile-Bizard. Neighbouring Laval (to the north of Montreal) has fluoridated its drinking water since 1958;[27] however Laval and Montreal are separate provincial administrative regions and presumably have separate water systems.
Montreal Rive-Sud, QC	Not fluoridated	We found no indication that drinking water in Montreal Rive-Sud (Montreal's South Shore, within which the largest city is Longueuil) is or has been fluoridated. This assignment makes sense considering that only 6.4% (489,420 people) of the population in the province of Quebec receive fluoridated water (according to the 2007 provincial estimates compiled by the Chief Dental Health Officer of Canada)[9] and this number is approximately equivalent to the population of Quebec City, which fluoridated its water until at least 2008 (491,140 according to the 2006 census).
Mauricie, QC (Shawinigan)	Not fluoridated	We found no indication that drinking water in Mauricie-Shawinigan, QC was fluoridated; however, Shawinigan is the location of one of Canada's main aluminum-producing companies, which merits comment with respect to fluoridation and oral health. One of the earliest events in the history of fluoridation was the observation of tooth mottling (now called fluorosis) among dental patients in Bauxite, Arkansas, a town owned by the Aluminum Company of America (ALCOA). A chemist with ALCOA identified high concentrations of fluoride in the water supply in Bauxite (a function of the aluminum processing), and it was subsequently determined that the fluoride was not only the etiological agent of mottled enamel but of protection from tooth decay.[4] The idea of artificially fluoridating drinking water to improve oral health followed. Also of note: the link between aluminum processing and fluoridation has endured in the form of an anti-fluoridation assertion that fluoridation is a "conspiracy" of aluminum companies which need to find some way to get rid of fluoride byproduct, which is difficult and expensive to dispose of properly.[26] A quotation posted on the website of the Fluoride Action Network, an anti-fluoride organization, stated "there is a lot of fluoride in Quebec waters because of the aluminum industry" and pointed to Shawinigan as one example. We have not been able to locate an estimate of fluoride content in the Shawinigan water supply.
Clarington, ON	Not fluoridated	The community of Clarington does not fluoridate its water. However, Clarington is located within the provincial region of Durham, and several Durham communities (located close to Clarington) do add fluoride to their water systems (specifically: Ajax, Brooklin, Oshawa [which supplies water to some residents of Courtice], Pickering, and Whitby). http://www.durham.ca/departments/health/facts_about/pdf/fluoride.pdf (accessed June 4, 2012)
Northumberland County, ON (Cobourg)	Not fluoridated	Cobourg (Northumberland County) does not appear to fluoridate its drinking water, though there may be small amounts of naturally-occurring fluoride in the water. http://www.hamiltontownship.ca/UserFiles/files/Cobourg%202010%20Annual%20Re port%20_2_.pdf (accessed June 4, 2012)
St. Catharines, ON	Not fluoridated	The Niagara Region, which includes St. Catharines, has not fluoridated its water since 1999 (http://www.niagararegion.ca/living/health_wellness/dental/fluoride-recommendations.aspx) (accessed June 4, 2012), though the drinking water that serves St. Catharines contains naturally-occurring fluoride at 0.14 ppm (not enough for health benefits). The 1999 date means that children in our sample (age 6-11 in 2007-2009) for the most part would not have been exposed.
Vancouver, BC	Not fluoridated	Vancouver has never fluoridated its water.[26] Along with Montreal, Vancouver is one of the only large Canadian cities never to have done so.
Kitchener-Waterloo, ON	Mixed	The actual site location is in Kitchener, which does not fluoridate its water (its water contains a small amount [0.1 ppm] of naturally-occurring fluoride).[9] However, neighbouring (adjacent) Waterloo began fluoridating its water in 1967,[22] though it voted to discontinue in 2010.
Williams Lake/Quesnel, BC	Mixed	According to a May 6, 2011 announcement (http://www.activewilliamslake.com/index.asp?p=1043) (accessed June 4, 2012), Williams Lake began fluoridating its water in 1969. Fluoridation appears to have been stopped in 2005 due to issues associated with upgrading equipment, and the 2011 announcement stated that public consultation would be initiated shortly re: whether to continue fluoridation once infrastructure is ready. This fluoridation hiatus means variable exposure for the children in our sample, who were age 6-11 in 2007-2009. Also, Quesnel does not appear to fluoridate its water (http://www.quesnel.ca/DocumentBank/Reports/2009/2009_Drinking.Water.Annual.Report.pdf) (accessed June 4, 2012). Although the data collection site location was in Williams Lake, we assumed based on the site label that participants were also drawn from Quesnel, making the overall fluoridation status mixed.

Note: Exact location of the clinic at each data collection site was obtained from Statistics Canada.

Table 2. Descriptive Statistics for Study Sample (Children Aged 6-11 Years, n=1,017) from the Canadian Health Measures Survey (Weighted Data Shown), Overall and by Fluoridation Status

Variable		Full Sample (n=1,017)	Fluoridation: No/Mixed (n=628)	Fluoridation: Yes (n=389)
dmftDMFT,* mean		2.42 (SD 3.1)	2.6 (SD 3.2)	2.2 (SD 3.0)
		n (%)	**n (%)**	**n (%)**
dmftDMFT, score	0	443 (43.6)	255 (40.6)	186 (47.9)
	1-2	219 (21.6)	136 (21.7)	83 (21.4)
	3+	354 (34.8)	237 (37.7)	119 (30.7)
Brush teeth at least twice/day	No	294 (28.9)	154 (24.5)	137 (35.3)
	Yes	723 (71.1)	474 (75.5)	252 (64.7)
Floss at least five times/week	No	896 (88)	545 (86.8)	350 (90.1)
	Yes	121 (11.9)	83 (13.2)	39 (9.9)
Visit dentist at least once/year	No	76 (7.4)	31 (4.9)	43 (11.1)
	Yes	941 (92.6)	597 (95.1)	346 (88.9)
Sugary drink daily	No	744 (73.1)	440 (70.1)	301 (77.4)
	Yes	273 (26.9)	188 (29.9)	88 (22.6)
Sex	Male	512 (50.4)	317 (50.4)	196 (50.3)
	Female	505 (49.6)	311 (49.6)	193 (49.7)
Highest household education	High school grad.	179 (17.6)	113 (18)	66 (16.9)
	Certif./diploma	449 (44.2)	272 (43.3)	177 (45.4)
	Bachelor's degree	267 (26.3)	170 (27.1)	98 (25.1)
	>Bachelor's degree	122 (12)	73 (11.6)	49 (12.6)
Income adequacy	Low	267 (26.3)	174 (27.7)	94 (24.3)
	Middle	267 (26.3)	148 (23.5)	117 (30.2)
	High	483 (47.5)	307 (48.9)	177 (45.5)
Owns home	No	258 (25.4)	143 (22.7)	113 (29.2)
	Yes	759 (74.6)	485 (77.3)	276 (70.8)
Dental insurance	No	198 (19.5)	123 (19.5)	76 (19.5)
	Yes	819 (80.5)	505 (80.5)	313 (80.5)
Born in Canada	No	77 (7.6)	50 (8.0)	27 (7.1)
	Yes	940 (92.4)	578 (92.0)	362 (93.0)
Lived in home at least 2 years	No	168 (16.5)	104 (16.5)	64 (16.5)
	Yes	849 (83.5)	524 (83.5)	325 (83.5)
Usually drinks tap water	No	430 (42.2)	283 (45.1)	149 (38.2)
	Yes	587 (57.8)	345 (54.9)	240 (61.8)
Source of tap water	Municipal system	861 (84.7)	114 (18.1)	44 (11.3)
	Other	156 (15.3)	514 (81.9)	345 (88.7)

* dmftDMFT=decayed, missing, filled teeth (deciduous or permanent).
Note: counts and percentages may not add exactly to 100% because of rounding.

Analysis

Data were accessed and analyzed within the Prairie Regional Research Data Centre at the University of Calgary. Stata software was used, and all analyses incorporated a sample weight as directed by Statistics Canada.

We first examined the association between fluoridation status and oral health, adjusting for covariates. Specifically, using ordinary least squares (OLS) regression, we regressed dmftDMFT on fluoridation status (yes/no), socio-economic variables (income, education, home ownership, dental insurance) and then further on additional covariates (tooth brushing, flossing, dental visit and sugary drink consumption). We next examined whether the association between fluoridation status and oral health varied by socio-economic position by regressing dmftDMFT on fluoridation status, socio-economic variables and socio-economic × fluoridation interaction terms, unadjusted and adjusted for covariates. To verify whether the assumption of linearity of the outcome variable in OLS was justified, we also ran models using multinomial logistic regression (MLR), with dmftDMFT divided into three groups: 0, 1-2 and 3 or more (categories guided by the distribution), where the latter two categories were compared against the base of zero. Finally, we reran OLS and MLR analyses among the subset of respondents who reported a) usually drinking tap water and b) having lived in their current home for at least 2 years.

We also computed the concentration index of education-related inequity in oral health by fluoridation status. The concentration index, which may be computed for socio-economic variables that are ordinal in nature, indicates how concentrated the health outcome (in this case, dmftDMFT) is along the distribution of socio-economic position (in this case, education),[29] thus complementing OLS and related techniques, which elucidate average effects.

OUTCOMES

There were a total of 1,081 children aged 6-11 in the CHMS. Other than the subsample analysis (for which n=525), our analyses are based on 1,017 children with complete data on all variables (94.1% of the full sample). Descriptive statistics for the study sample are provided in Table 2. Estimates for the full sample (column 1) illustrate a relatively high socio-economic status overall: for example, nearly half of respondents lived in households that fell into the highest income adequacy category, and nearly three quarters lived in households where the home was owned (versus rented).

Table 3 shows the results of the OLS regression, main effects models (unadjusted [Model A] and adjusted for covariates [Model B]) and models containing interaction terms (unadjusted [Model C] and adjusted for covariates [Model D]). The main effects models show a marginal effect of fluoridation whereby fluoridation was associated with fewer dmftDMFT. Higher household education and brushing one's teeth at least twice/day were also associated with fewer dmftDMFT. Having visited the dentist at least once in the past year was associated with increased dmftDMFT, which probably reflects oral health problems prompting a visit to the dentist. Marginal effects were observed for the middle income adequacy category (associated with higher dmftDMFT compared with the low income adequacy category) and home ownership (associated with fewer dmftDMFT compared with renting one's home).

Table 3. Results of Ordinary Least Squares Regression Among Children Aged 6-11 (n=1,017) from the Canadian Health Measures Survey

Variable	Model,* Coefficient (95% confidence interval) A	B	C	D
Fluoridation status (reference=no/mixed)				
Yes	-0.53 (-1.1 to 0.02)**	-0.49 (-1.0 to 0.03)**	-1.6 (-3.4 to 0.28)**	-1.6 (-3.4 to 0.12)**
Household education (reference=high school graduation)				
>Bachelor's degree	-1.3 (-2.4 to -0.3)†	-1.2 (-2.2 to -0.09)†	-1.8 (-3.2 to -0.4)†	-1.6 (-3.1 to -0.21)†
Bachelor's degree	-1.7 (-2.5 to -0.9)‡	-1.6 (-2.4 to -0.8) ‡	-2. 0 (-3.2 to -1.0)‡	-2.0 (-3.0 to -0.97)‡
Certif./diploma	-0.57 (-1.5 to 0.32)	-0.58 (-1.4 to 0.25)	-1.3 (-2.4 to -0.27)†	-1.3 (-2.3 to -0.37)‡
Income adequacy (reference=low)				
High	0.47 (-0.30 to 1.2)	0.40 (-0.32 to 1.1)	1.2 (0.24 to 2.1)†	1.0 (0.16 to 1.9)†
Mid	0.69 (-0.12 to 1.5)**	0.65 (-0.10 to 1.4)**	0.90 (0.04 to 1.8) †	0.80 (-0.04 to 1.6)**
Home ownership (reference=rent)				
Own	-0.79 (-1.5 to -0.05)†	-0.65 (-1.4 to 0.07)**	-0.82 (-1.6 to 0.002)**	-0.77 (-1.6 to 0.04)**
Dental insurance (reference=no)				
Yes	-0.07 (-0.80 to 0.67)	-0.37 (-1.1 to 0.35)	-0.42 (-1.4 to 0.52)	-0.64 (-1.5 to 0.26)
Fluoridation × household education (interaction term)				
Fl × >Bach. degree	–	–	1.4 (-0.52 to 3.2)	1.3 (-0.50 to 3.2)
Fl × Bach. degree	–	–	1.2 (-0.30 to 2.7)	1.1 (-0.34 to 2.5)
Fl × Cert./diploma	–	–	2.0 (0.30 to 3.6)†	2.0 (0.39 to 3.6)†
Fluoridation × income adequacy (interaction term)				
Fl × high income adequacy	–	–	-1.8 (-3.4 to -0.24)†	-1.7 (-3.2 to -0.23)†
Fl × mid-income adequacy	–	–	-0.71 (-2.4 to 1.02)	-0.55 (-2.2 to 1.1)
Fluoridation × home ownership (interaction term)				
Fl × own	–	–	0.20 (-1.2 to 1.6)	0.41 (-0.94 to 1.8)
Fluoridation × dental insurance (interaction term)				
Fl × dental insurance	–	–	0.75 (-0.63 to 2.1)	0.54 (-0.72 to 1.8)
Brushes teeth at least twice/day (reference: no)				
Yes	–	-1.1 (-1.8 to -0.4)‡	–	-1.1 (-1.7 to -0.46)‡
Flosses teeth at least five times/week (reference: no)				
Yes	–	-0.18 (-0.76 to 0.40)	–	-0.22 (-0.82 to 0.37)
Visited dentist at least once in the past year (reference: no)				
Yes	–	1.8 (1.0 to 2.7)‡	–	1.8 (1.0 to 2.6)‡
Sugary drink at least once/day (reference: no)				
Yes	–	0.49 (-0.16 to 1.2)	–	0.47 (-0.15 to 1.1)
Born in Canada (reference: no)				
Yes	–	-0.15 (-0.89 to 0.59)	–	-0.20 (-0.95 to 0.54)

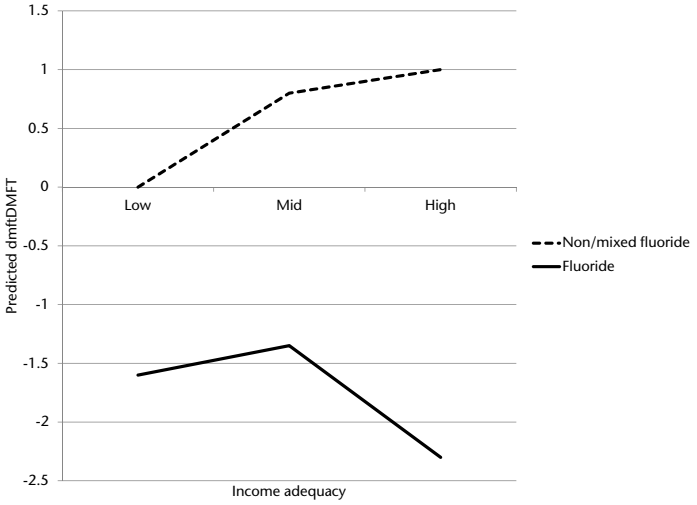
* Outcome variable is number of decayed, missing or filled teeth, deciduous or permanent (dmftDMFT). Model A: dmftDMFT regressed on fluoridation status and socio-economic status (SES) variables. Model B: dmftDMFT regressed on fluoridation status and SES variables, adjusted for covariates. Model C: dmftDMFT regressed on fluoridation status, SES variables and fluoridation × SES interaction terms. Model D: dmftDMFT regressed on fluoridation status, SES variables and fluoridation × SES interaction terms, adjusted for covariates.
**p<0.10, †p<0.05, ‡p<0.01

Two significant fluoridation status × socio-economic position interaction effects were observed (Models C and D): fluoridation status × certificate/diploma (household education) and fluoridation status × high income adequacy. To interpret these interactions, we used coefficients from model D (Table 3) to plot predicted dmftDMFT by income adequacy (Figure 1a) and by household education (Figure 1b) in the two fluoride conditions. Figure 1a shows that in the no/mixed fluoridation condition there was a positive income gradient whereby dmftDMFT was higher (worse) in medium and high income adequacy households than in low. In the fluoridation condition, dmftDMFT was lower (better) in all cases, but the negative gradient was such that the outcome was particularly reduced (improved) in the high income adequacy category (relative to the low income adequacy category in the no/mixed fluoridation condition). For education (Figure 1b), the no/mixed fluoridation condition shows the protective gradient effect of education on dmftDMFT. In the fluoridation condition, the gradient was dampened such that dmftDMFT was slightly lower (better) in the higher education conditions and markedly better in the lowest education (high school graduate or less) condition, relative to lowest education in the no/mixed fluoridation condition.

The results from the MLR analysis were substantively similar to those from the OLS models; thus we do not present them in full. Statistically significant effects were predominantly observed in the comparison between the two extreme categories of the outcome variable (3 or more dmftDMFT versus 0), thus we highlight some effects from that comparison in the adjusted models. We observed a protective effect of fluoridation; that is, fluoridation was associated with significantly reduced odds of having 3 or more dmftDMFT versus 0 (coefficient = -0.44, 95% confidence interval [CI] -0.81 to -0.06, p=0.024). Higher household education (p=0.001) and brushing at least twice daily (p=0.001) were each associated with reduced odds of having 3 or more dmftDMFT (versus 0); having visited the dentist at least once in the past year was associated (p=0.006) with increased odds of having 3 or more dmftDMFT (versus 0). In the adjusted models containing interaction terms, the fluoridation status by high income adequacy term was statistically significant (coefficient -1.19, 95% CI -2.3 to -0.06, p=0.039, similar pattern to the OLS models). The interaction between fluoridation and household education observed in the OLS models was not statistically significant in the MLR model (p=0.14).

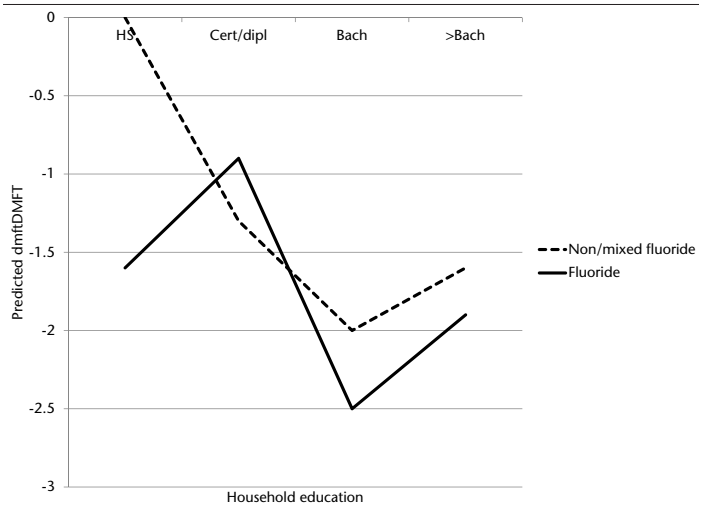
We reran both OLS and MLR models for the subsample of respondents who reported that they usually drank tap water and that they had lived in their current home for at least 2 years (n=525). Main effects findings were substantively similar; for example, fluoridation had a protective effect that was marginally significant in the adjusted OLS model (coefficient = -0.72, 95% CI -1.5 to 0.06, p=0.07) and significant at the conventional 0.05 level in the MLR model (coefficient = -0.87, 95% CI -1.4 to -0.33, p=0.001 for effect of fluoridation on odds of 3 or more versus 0 dmftDMFT). No interaction terms were statistically significant in the OLS subsample models; in the MLR subsample models, there was a marginally significant interaction between fluoridation status and certificate/diploma (household education) (coefficient 1.68, 95%

Figure 1a. Predicted dmftDMFT relative to lowest income adequacy in non/mixed fluoridation communities



Coefficients taken from Model D in Table 3. No/mixed fluoride condition: 0, 0.8 and 1.0 for low, medium, and high income adequacy, respectively. Fluoride condition: -1.6, -1.35 [(-1.6) + (0.8) + (-0.55)] and -2.3 [(-1.6) + (1.0) + (-1.7)] for low, medium and high income adequacy, respectively.

Figure 1b. Predicted dmftDMFT relative to lowest household education (high school graduate or less) in non/mixed fluoridation communities



Coefficients taken from Model D in Table 3. No/mixed fluoride condition: 0, -1.3, -2.0 and -1.6 for high school, certificate/diploma, Bachelor's degree and >Bachelor's degree, respectively. Fluoride condition: -1.6, -0.9 [(-1.6) + (-1.3) + (2.0)], -2.5 [(-1.6) + (-2.0) + (1.1)] and -1.9 [(-1.6) + (-1.6) + (1.3)] for high school, certificate/diploma, Bachelor's degree and >Bachelor's degree, respectively.

CI -0.22 to 3.6, p=0.084, similar pattern to fluoridation × education interaction observed elsewhere), for effect on odds of 1-2 versus 0 dmftDMFT in adjusted models.

The concentration index of inequality in dmftDMFT by household education was -0.18 (95% CI -0.28 to -0.08) in the fluoridated communities and -0.16 (95% CI -0.23 to -0.09) in the no/mixed fluoridated communities (as reference, the index is bounded by -1 and +1). Both values differ significantly from zero in the negative direction, indicating a disproportionate concentration of dmftDMFT within lower education households in both fluoridated and non/mixed fluoridated communities. The two values do not differ from one another.

DISCUSSION

Among children aged 6 to 11 in the CHMS, we detected an inverse association between community drinking water fluoridation status and oral health outcomes, such that fluoridation was associated with fewer decayed, missing and filled teeth. Interpretation of interaction terms, used to test for a differential effect of fluoridation on dmftDMFT by socio-economic circumstances, indicated a beneficial effect across socio-economic categories that appeared particularly in the high income adequacy and the lower education households. The concentration index of education-related inequity indicated that dmftDMFT were disproportionately concentrated in lower education households, though this did not differ by fluoridation status.

We seek to interpret these findings in light of our objective, which was to understand the relation between fluoridation and oral health inequities. First, the protective main effect of fluoridation was observed in both OLS (marginal significance) and MLR models, was robust to adjustment for four socio-economic measures and four oral-health-related covariates, was particularly strong for more severe oral health outcomes (3 or more dmftDMFT versus 0) and, despite reduced statistical power, was maintained in the smaller subsample for which the exposure measurement was arguably improved. This effect of fluoridation is thus consistent with the assertion that fluoridation benefits everyone, regardless of socio-economic circumstances and above and beyond dental-health-related behaviours.

In terms of the equity of fluoridation, our findings tell a more nuanced story. As noted, social inequities in health refer to differences in health between (in this case) socio-economic groups where the differences favour those higher in socio-economic circumstances and are seen as unfair and avoidable.[10,12] From this perspective, an intervention that is equitable would have a proportionally greater impact among those of lower socio-economic circumstances, whose health status is poorer to begin with. This is the pattern we observed with household education: fluoridation was associated with better oral health than non/mixed fluoridation across various education levels, but particularly among those in the lowest education category. For income, on the other hand, although benefits were seen across categories, the apparently largest benefit was for those in the highest income adequacy group. As noted by Harper et al.,[29] the study of health inequalities involves value judgements about what is fair or socially acceptable, and these value judgements may lead to different interpretations of the same data. Some may view our income effect as non-equitable because the higher income adequacy group (who are not socio-economically deprived) appear to be disproportionately benefitting from fluoridation. Others may view it as equitable because the greatest benefit was seen in the group with the poorest health status.

When judging the benefits of an intervention, one must consider *both* differential impact across socio-economic groups and overall impact on the population. For example, if an intervention produced no benefit for the lowest socio-economic group and some benefit for the higher socio-economic groups, health inequalities would increase but average or overall population health would improve (which many would view positively). According to our findings, better health outcomes in the fluoridation group were

apparent across all income categories, thereby resembling a distribution shift as described by Rose.[1] Because all income groups were better off (lower dmftDMFT) in the fluoridation condition, and none was worse off in an absolute sense, we believe that the effect of fluoridation can be viewed as a positive one. The alternative position – to emphasize the negative income gradient in the fluoridated group, favouring the rich – would require one to privilege equity as the dominant principle over population health.[30] Our findings also enable reflection on the libertarian critique of water fluoridation: one could argue that impingement on personal liberty (in the form of fluoridation) is justified, because harm associated with impingement is offset by health gains for the population as a whole.[30]

Whereas our OLS and MLR analyses allowed us to estimate the average associations among fluoridation status, socio-economic variables and oral health, the concentration index provides additional information about the distribution of the oral health outcome across the population's socio-economic distribution. Our computation confirmed that dmftDMFT is disproportionately concentrated among children from lower-education households, in both fluoridated and no/mixed fluoridation communities. By way of improving the interpretability of the index, a computation provided in O'Donnell et al.[31] was used and yielded the percentage of dmftDMFT that would need to be redistributed from the lower to the higher education categories to achieve an equal distribution of dmftDMFT. The values are 13.4% and 11.8% in fluoridated and no/mixed fluoridation communities, respectively. The concentration index did not differ in fluoridated versus no/mixed fluoridation communities, suggesting that fluoridation is not sufficient to offset the disproportionate concentration of dmftDMFT in lower education households.

Against the backdrop of our nuanced findings about the equitability of fluoridation, we consider the assertion made by some that there are other viable options, aside from fluoridation, to address oral health inequities, namely, programs to provide dental resources to those in need.[3] First, the strategies that have been suggested as alternatives to fluoridation (e.g., subsidized dental treatment, prevention programs such as fluoride rinse delivered in "high needs" schools) usually focus on the economic dimension of socio-economic circumstances – i.e., low income status. However, as seen in these data, the relation between household income adequacy and oral health is not a straightforward inverse gradient; consequently, programs targeted at lower income individuals may miss some sections of the population with problematic oral health profiles. This does not apply to drinking water fluoridation, which is non-exclusive in nature. Second, depending on how a targeted program is delivered, there may be potential for stigmatization of recipients. Publicly identifying "needy" groups can (inadvertently) perpetuate marginalization of particular groups in a way that a universal strategy such as community water fluoridation does not. Third, the development and implementation of alternative strategies for addressing oral health inequities can be very costly, and this needs to be weighed against the costs (and benefits) of community water fluoridation over the long term. Overall, our findings that fluoridation is beneficial for the population as a whole, and across socio-economic groups, suggest that a universal approach is preferable to a targeted approach in these circumstances.

The limitations of our study include the cross-sectional nature of the data, which do not allow us to discern fluoride's impact on oral health outcomes, and the residual inaccuracies of our fluoride exposure variable. Nonetheless, we were able to detect a beneficial main effect of fluoridation on the tooth-level caries of children from a national sample, a benefit across socio-economic groups and an equitable effect to the extent that those with the worst outcomes benefited most, on average. Polarized viewpoints on drinking water fluoridation as a population/public health intervention have led to its elimination or uncertain status in many Canadian communities.[6] Our findings support its continued use.

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RÉSUMÉ

Objectifs : L'un des arguments en faveur de la fluoration de l'eau potable est qu'il s'agit d'une mesure dont l'impact sur la santé buccodentaire est équitable. Nous avons examiné l'association entre l'exposition à la fluoration et les inégalités en santé buccodentaire chez les enfants canadiens.

Participants, lieu et intervention : Nous avons analysé les données de 1 017 enfants de 6 à 11 ans tirées du 1er cycle de l'Enquête canadienne sur les mesures de la santé, une enquête transversale représentative à l'échelle du pays qui comporte un examen clinique de la santé buccodentaire et un entretien avec le ménage. Notre mesure de résultat était le décompte des dents cariées, manquantes (en raison de caries ou de maladies parodontales) ou plombées, temporaires ou permanentes (dcmpDCMP). Les données ont été analysées par régression logistique linéaire (méthode ordinaire des moindres carrés) et multinomiale; nous avons aussi calculé l'indice de concentration pour les inégalités en santé buccodentaire liées à la scolarité. La fluoration ou non de l'eau (l'intervention) a été déterminée selon l'emplacement du site de collecte des données.

Résultats : La fluoration était associée à une meilleure santé buccodentaire (moins de dcmpDCMP), compte tenu de diverses variables socioéconomiques et comportementales, et cet effet était particulièrement fort pour les problèmes de santé buccodentaire les plus graves (trois dcmpDCMP ou plus). L'effet de la fluoration sur les dcmpDCMP a été observé dans toutes les catégories de revenu et de scolarité, mais semblait particulièrement prononcé au sein des ménages dont les niveaux de scolarité et de revenu étaient inférieurs. Les dcmpDCMP étaient démesurément concentrées dans les ménages à faible niveau de scolarité, mais ce résultat ne variait pas selon que leur eau était fluorée ou non.

Conclusion : L'effet principal de la fluoration sur les dcmpDCMP, et son effet bénéfique dans tous les groupes socioéconomiques, montrent qu'il s'agit d'une intervention en santé des populations à la fois bénéfique et justifiée. La fluoration était équitable au sens où ses avantages étaient particulièrement apparents dans les groupes dont le profil de santé buccodentaire était le pire, mais la nature des résultats devrait nous inciter à tenir compte des valeurs qui sous-tendent le verdict d'équité.

Mots clés : Canada; fluoration; santé buccodentaire; facteurs socioéconomiques