

Available online at www.sciencedirect.com

Public Health

journal homepage: www.elsevier.com/puhe

Original Research

Exploring the short-term impact of community water fluoridation cessation on children's dental caries: a natural experiment in Alberta, Canada



L. McLaren ^{a,*}, S. Patterson ^b, S. Thawer ^{b,c}, P. Faris ^d, D. McNeil ^{a,e},
M.L. Potestio ^a, L. Shwart ^f

^a Department of Community Health Sciences and O'Brien Institute for Public Health, University of Calgary, 3280 Hospital Dr. NW, Calgary, Alberta, T2N 4Z6, Canada

^b School of Dentistry, Faculty of Medicine and Dentistry, University of Alberta, Canada

^c Department of Community Health Sciences, University of Calgary, Canada

^d Research Facilitation, Research Priorities and Implementation, Alberta Health Services, Canada

^e Strategic Clinical Networks, Alberta Health Services and Faculty of Nursing, University of Calgary, Canada

^f Formerly with the Provincial Oral Health Office, Alberta Health Services, Canada

ARTICLE INFO

Article history:

Received 2 March 2016

Received in revised form

23 December 2016

Accepted 28 December 2016

Available online 7 February 2017

Keywords:

Fluoridation

Public health

Dental surveys

Canada

ABSTRACT

Objectives: Dental caries (tooth decay) is common and can be serious. Dental caries is preventable, and community water fluoridation is one means of prevention. There is limited current research on the implications of fluoridation cessation for children's dental caries. Our objective was to explore the short-term impact of community water fluoridation cessation on children's dental caries, by examining change in caries experience in population-based samples of schoolchildren in two Canadian cities, one that discontinued community water fluoridation and one that retained it.

Study design: We used a pre-post cross-sectional design.

Methods: We examined dental caries indices (deft [number of decayed, extracted, or filled primary teeth] and DMFT [number of decayed, missing, or filled permanent teeth]) among grade 2 schoolchildren in 2004/05 and 2013/14 in two similar cities in the province of Alberta, Canada: Calgary (cessation of community water fluoridation in 2011) and Edmonton (still fluoridated). We compared change over time in the two cities. For Calgary only, we had a third data point from 2009/10, and we considered trends across the three points.

Results: We observed a worsening in primary tooth caries (deft) in Calgary and Edmonton, but changes in Edmonton were less consistent and smaller. This effect was robust to adjustment for covariates available in 2013/14 and was consistent with estimates of total fluoride intake from biomarkers from a subsample. This finding occurred despite indication that treatment activities appeared better in Calgary. The worsening was not observed for permanent teeth. For prevalence estimates only (% with >0 deft or DMFT), the three data points in Calgary suggest a trend that, though small, appears consistent with an adverse effect of fluoridation cessation.

* Corresponding author. Tel.: +1 403 210 9424.

E-mail address: lmclaren@ucalgary.ca (L. McLaren).

<http://dx.doi.org/10.1016/j.puhe.2016.12.040>

0033-3506/© 2017 The Authors. Published by Elsevier Ltd on behalf of The Royal Society for Public Health. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Conclusions: Our results suggest an increase in dental caries in primary teeth during a time period when community fluoridation was ceased. That we did not observe a worsening for permanent teeth in the comparative analysis could reflect the limited time since cessation. It is imperative that efforts to monitor these trends continue.

© 2017 The Authors. Published by Elsevier Ltd on behalf of The Royal Society for Public Health. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

More than half of children in Canada (aged 6–11 years) and the US (aged 5–11 years) are affected by dental caries (tooth decay).^{1,2} Children with extensive caries could require treatment in the hospital.^{3–5} Social inequities in oral health problems are significant.^{2,6,7} Dental caries in childhood can affect the growth of adult teeth and contribute to sleeping problems, behavioral and learning problems, and poor school performance.^{5,8}

Caries is largely preventable, and one avenue for prevention is appropriate exposure to fluoride. Community water fluoridation (CWF) refers to the controlled addition of a fluoride compound to a public water supply for the purpose of preventing tooth decay in the population.⁹ Early studies of CWF in the 1940s and 1950s showed significant positive impact in preventing tooth decay.¹⁰ However, important changes have occurred. First, unlike the 1940s and 1950s when drinking water was the only significant source of fluoride, we are now exposed to multiple sources, most notably fluoride toothpaste.¹¹ Second, although tooth decay was previously nearly universal and quite extensive for most, it is now less widespread and the distribution is skewed with a minority of children accounting for a majority of problems.¹² Systematic reviews support the benefits of CWF for the prevention of tooth decay; however, the quantity and quality of contemporary evidence is recognized to be the modest.^{13,14}

Another feature of the contemporary CWF landscape is instances of cessation. A systematic review¹⁵ identified published research on 15 instances of CWF cessation in 13 countries. Overall, results were mixed; however, of the nine studies with the highest methodological quality of those included in the review, five showed an increase in dental caries post cessation. The effect was apparent within 2–3 years of cessation in two of those studies.^{16,17}

Overall, our knowledge of the dental caries impact of fluoridation cessation in different contexts is limited. This is problematic because the number of communities in some regions, such as Canada, that are reconsidering CWF appears to be increasing.^{18,19} If CWF is contemporarily effective in reducing the tooth decay, it is important to document it, so that informed debates can take place during instances of CWF decision-making. If it is no longer effective, it is important to know that too, so that alternative options to improve oral health can be identified.

The purpose of this study was to explore the short-term impact of CWF cessation in Calgary, Canada, compared with Edmonton, Canada. In Calgary, CWF was discontinued in May

2011, following a City Council vote, after having been in place since 1991. In Edmonton, CWF began in 1967 and remains in place. Our selection of comparison community was informed by a related study²⁰ wherein local fluoridation stakeholders expressed that a comparative study of Calgary and Edmonton would provide the most credible evidence for local decision-making. Based on existing cessation research^{16,17} and the time frame of our study, we hypothesized that we would see some indication (not necessarily statistically significant) of an increase in dental caries in Calgary, where CWF was stopped, relative to Edmonton where CWF remains in place.

Methods

Design and study locations

We used a pre-post cross-sectional design with comparison community. Calgary ('CWF cessation') and Edmonton ('CWF continued') are well matched: as the two largest cities in the province of Alberta, they are both large urban centers (2011 populations approximately 1.1 million for Calgary and 810,000 for Edmonton) with diverse demographic profiles. Based on 2011 census data, the percentage of children aged 5–9 years living in single parent families was 15.1% in Calgary and 19% in Edmonton;²¹ and the percentage who mainly speak a language other than English or French at home was 14% in Calgary and 9% in Edmonton.²² Based on the 2011 National Household Survey,⁸ the percentage of children aged 5–9 years of visible minority status was 38.1% in Calgary and 28.7% in Edmonton,²⁴ and the percentage of children aged 0–9 years^h who live in a household with an education level of a bachelor's degree or higher was 53.6% in Calgary and 40.6% in Edmonton.²⁵ The percentage of children aged 5–9 years living in families that moved within the last 5 years was similar: 53.1% (Calgary) and 53.6% (Edmonton).²⁶

Annual water quality reports obtained from the two cities for 2005–2013 confirm generally the optimal levels of fluoride in Calgary drinking water (range 0.59–0.89 mg/L) up until cessation in 2011 when levels declined (range 0.07–0.30 mg/L). In Edmonton, average and median values mostly confirm optimal levels of fluoride in water, with some important short-term exceptions where fluoridation was lower than the

^g Following the 2006 national census, the mandatory long-form census was discontinued, and its replacement (the National Household Survey) was voluntary and may have some bias.²³

^h An estimate for the 5–9 year age group could not be generated for the household education variable.

optimal (see Appendix A). Those exceptions would tend to bias effects toward the null.

Target population and sampling

The target population was grade 2 children (approximately aged 7 years) attending school in the Public or Catholic school systems in Calgary and Edmonton. These two systems captured more than 90% of the Alberta schoolchildren in 2013/14.²⁷ We selected grade 2 because children of that age, on average, have both primary and some permanent teeth available for assessment. The mean and range for age (in years) across the four data sets was: 7.09 (range 5–12) for Calgary 2004/05, 7.08 (range 5–10) for Edmonton 2004/05, 7.07 (range 4–12) for Calgary 2013/14, and 7.03 (range 3–13) for Edmonton 2013/14. Outlier values were retained because they did not influence effects (see adjusted regression results below).

Data were collected from population-based samples drawn during the 2004/05 (pre cessation, as part of health region surveillance activities) and 2013/14 (post cessation) school years (i.e. October–May/June) in Calgary and Edmonton. In Calgary, pre cessation (2004/05), a stratified random sample was used, with strata based on neighborhood income level of school location. The response rate was 60%.²⁸ For the pre cessation Edmonton survey (2004/05), all elementary schools in the two school boards were invited to participate, and within each school, a majority (80–100%) of children were sampled. The response rate was approximately 89%. In Calgary and Edmonton post cessation (2013/14), a stratified random sample was used, with strata based on neighborhood income level of school location. The overall school-level response rate was 57.3% in Calgary and 54.1% in Edmonton, and the overall student-level response rate within participating schools was 49.1% in Calgary and 47.0% in Edmonton. For Calgary only, we had a third data point, from 2009/10.^{29,30} The 2009/10 survey was also conducted by the former Calgary Health Region as part of their surveillance activities.²⁹ Like the other surveys, data were gathered from a stratified random sample of children, with strata based on median neighborhood income where the school was located; within sampled schools, all children of eligible grades were invited to participate, and the response rate was 81%.²⁹ The mean and range for age (in years) for this survey was 6.95 (range 6.9–7.0). We developed sampling weights for each survey, such that each survey sample was the representative of the underlying target population at that time. Our weights accounted for both the probability of selection (as per the sampling frame) as well as the probability of non-response. This approach enabled us to handle missing observations within the framework of our survey sampling approach.³¹ Pre cessation and post cessation, data were collected via oral examinations conducted at school by trained and calibrated assessment teams consisting of a registered dental hygienist and a clerk. Decayed, missing/extracted, and filled teeth and tooth surfaces (primary and permanent) were recorded, following the World Health Organization criteria.³² The 2013/14 data followed the protocol from the Iowa Fluoride Study,³³ which is based on the WHO criteria. Presence/absence of dental sealants was also recorded. Teeth that were missing due to natural exfoliation

(primary) or not yet erupted (permanent) were omitted from calculations.³² Following each exam, a note was sent home to parents that indicated the outcome of the exam and provided a resource list of dental treatment options. Written parental consent and verbal child assent were secured.

In 2013/14 only, a questionnaire was completed by parents to gather information on socio-demographic, dental-related, and behavioral variables. Validated and field-tested questions were drawn from Statistics Canada³⁴ and the US Centers for Disease Control and Prevention—Oral Health Division.³⁵ The questionnaire was pilot-tested and small changes were made before the use (e.g. we added ‘apple juice’ as an example of fruit juices).

Also in 2013/14 only, fingernail clippings were taken from a small random subsample ($n = 35$) in each city.³⁶ Fingernail clippings provide a valid and reasonably non-intrusive biomarker for recent fluoride intake.³⁷ The fluoride concentrations of the nail clippings (8–11 mg) were determined after overnight, HMDS-facilitated diffusion using the ion-specific electrode and a miniature calomel reference electrode both coupled to a potentiometer. Fluoride standards were prepared in triplicate and diffused in the same manner as the nail clippings.³⁶ Analysis of clippings was blind to city and CWF status.

Analysis

In this article, we report on tooth-level summary measures; namely deft (number of decayed, extracted, or filled primary teeth) and DMFT (number of decayed, missing, or filled permanent teeth). Because the distributions of deft and DMFT are positively skewed with a large number of zero values, we considered prevalence (% with deft/DMFT > 0), means, and means for those with non-zero values. Data on caries patterns on specific tooth surfaces are reported elsewhere.³⁸

We examined change over time (2004/05–2013/14) in Calgary (CWF cessation), compared with that in Edmonton (CWF-continued). We first computed crude estimates (mean or percent, 95% confidence interval [CI]) for deft and DMFT for 2004/05 and 2013/14, for Calgary and Edmonton. Differences between the two cities in change over time were confirmed using regression (Poisson [regular or zero-inflated] or logistic) with the outcome measure (e.g. deft, DMFT) regressed on year (2013/14 vs 2004/05), city (Calgary vs Edmonton), age, and year \times city interaction. For Calgary only, we also examined trends across the three available data points (2004/05, 2009/10, and 2013/14).

Second, within the context of the comparative analysis, to explore the extent to which crude estimates for deft and DMFT could reflect socio-demographic and behavioral differences between the samples, we compared Calgary and Edmonton on information from the 2013/14 questionnaire. Statistically significant differences between the samples were accounted for by computing adjusted estimates (mean or percent, 95% CI) for 2013/14 using the ‘adjust’ command in Stata, following a linear regression containing all covariates.

Third, to explore the potential role of treatment and preventive services in contributing to any effects observed, we examined trends over time (2004/05–2013/14) in Calgary and Edmonton on: 1) a variable that disaggregates deft/DMFT into

treated (fillings, extractions) and untreated (decay) components; and 2) proportion with protective dental sealants. We also considered local dental public health programming in the two cities.

Finally, we considered the results of the analysis of fingernail clippings to see whether they were consistent with findings from the oral examinations for Calgary and Edmonton.

The study received approval from the Conjoint Health Research Ethics Board at the University of Calgary (ID E-25219) and the Health Research Ethics Board at the University of Alberta (ID Pro00037808).

Results

Table 1 shows the crude summary oral health metrics in 2004/05 and 2013/14 in Calgary and Edmonton. For primary teeth (deft), there was a significant increase between 2004/05 and 2013/14 in Calgary (for all three deft metrics) and Edmonton (for overall deft only). For the overall mean deft and the mean deft among those with deft > 0, the absolute magnitude of change was larger in Calgary, as confirmed by a statistically significant year × city interaction.

Crude trends for permanent teeth (DMFT) are also shown in Table 1. There was a statistically significant decrease in Calgary, which was not present in Edmonton, and which was confirmed by a statistically significant year × city interaction for mean DMFT and percentage with DMFT > 0.

Trends across the three data points (2004/05, 2009/10, and 2013/14) for Calgary only did not reveal any consistent or discernable difference in the slope of the incline between 2004/05 and 2009/10 (pre cessation), vs between 2009/10 and 2013/14 (largely post cessation), when we considered mean (average) deft. However, when we considered prevalence (i.e. % with one or more deft), there was an indication of a small increase in slope (the worsening speeds up) in the latter period (2009/10–2013/14) compared with the former period (2004/05–2009/10). For DMFT prevalence, we likewise observed a small decrease in slope (the improvement slows down) in the latter period (2009/10–2013/14) compared with the former period (2004/05–2009/10). Trends across the three data points for deft and DMFT prevalence in Calgary only are shown in Fig. 1. Covariate information for Calgary and Edmonton from the 2013/14 questionnaire is shown in Table S1 (there was no questionnaire in 2004/05). Based on Pearson's chi-squared statistic ($P < 0.05$), the Calgary sample was significantly higher than the Edmonton sample on: % excellent/good health of child's mouth; % brush twice/day or more; % who visited the dentist within the past year; % eat fruit/vegetables once/day or more; % received fluoride treatment at the dentist; % household education of bachelor's degree or higher; % who own their home; and % 'white' ethno-cultural background. Edmonton was significantly higher than Calgary on: % who visit the dentist only for emergencies or never; and % who drink sugary drink once/day or more.

Adjusted estimates (mean or %, 95% CI) for primary tooth (deft) and permanent tooth (DMFT) metrics are shown in Table S2: 2013/14 estimates were adjusted for sample differences

shown in Table S1. Adjustment did not materially change the 2013/14 deft and DMFT estimates.

Table 2 shows trends over time in treated and untreated components of the deft/DMFT. The proportion with 'complete caries care' (no untreated decay, but one or more fillings/extractions) showed a significant increase in Calgary, but a significant decrease in Edmonton. Conversely, the proportion with 'no caries care' (one or more instances of untreated decay, but no fillings/extractions) showed a decrease in Calgary and an increase in Edmonton. These patterns were confirmed in binary logistic regression for complete caries care vs other, and for no caries care vs other (two separate analyses), regressed on year, city, age, and year × city interaction, which showed statistically significant interaction term (interaction term odds ratio from logistic regression predicting complete caries care: 2.53 [2.04, 3.13], $P < 0.001$; interaction term odds ratio from logistic regression predicting no caries care: 0.38 [0.28, 0.52], $P < 0.001$). Therefore, treatment appears to have increased in Calgary but not in Edmonton.

The proportion of children with protective dental sealants showed no significant differences between cities or between time points in either city: 26% (24%–29%) for Calgary 2004/05; 24% (22%–26%) for Calgary 2013/14; 27% (26%–29%) for Edmonton 2004/05; and 27% (24%–31%) for Edmonton 2013/14.

Information on dental public health programming was obtained from dental public health managers in the two regions. Programming in both areas is targeted to schools located in lower socio-economic communities. Calgary has had a targeted fluoride varnish program in place since at least 2002/03, which is delivered approximately yearly. Post CWF cessation, a subset of the targeted schools in Calgary was targeted further by a dental health bus initiative which travels to schools to deliver sealants and fluoride varnish. In Edmonton, a targeted fluoride varnish program has been in place since approximately 2000, which since 2012 has been accompanied by a targeted sealant program. Using aggregate information from the 2013/14 programs (individual-level data was not available), approximately 28% of our Calgary sample attended a school that participated in the targeted fluoride varnish program, and approximately 12.5% attended a school that also participated in the dental health bus program. For Edmonton, approximately 23% of our sample attended a school that participated in the targeted program. Thus, it appears that exposure to these programs was broadly similar across our samples.

Based on 35 samples of fingernail clippings in each city (total 70 samples) at post cessation (2013/14), the mean fluoride estimate for Calgary (mean = 1.90 ng/mg F, 95% CI: 1.63–2.17) was significantly lower than the mean estimate in Edmonton (mean = 3.57 ng/mg F, 95% CI: 3.02–4.12). The median (and range) were 1.77 (0.80–4.04) for Calgary, and 3.27 (1.36–8.63) for Edmonton.

Discussion

We observed an increase in primary tooth dental caries in Calgary that occurred over a time period when CWF was discontinued in that city (2004/05–2013/14). Although an increase was also observed in Edmonton, where CWF remains in

Table 1 – Means and percentages (weighted estimates) for dental caries indices: deft (decayed, extracted, or filled primary teeth) and DMFT (decayed, missing, or filled permanent teeth), grade 2 students in Calgary and Edmonton, 2004/05 and 2013/14.

Dental caries index	Calgary 2004/05 Mean or percentage (95% CI), n	Calgary 2013/14 Mean or percentage (95% CI), n	Calgary Δ	Edmonton 2004/05 Mean or percentage (95% CI), n	Edmonton 2013/14 Mean or percentage (95% CI), n	Edmonton Δ	Year \times city interaction term: rate ratio or odds ratio (95% CI), P-value ^a
Primary teeth							
Mean deft	1.62 (1.41, 1.83), n = 599	2.67 (2.51, 2.83), n = 2778	$\Delta = 1.05^*$	2.45 (2.33, 2.57), n = 6445	2.79 (2.59, 2.99), n = 1907	$\Delta = 0.34^*$	RR ^{\times} = 1.37 (1.25, 1.51), P < 0.001*
Percentage with deft ≥ 1	49% (43%, 54%), n = 599	57% (55%, 59%), n = 2778	$\Delta = 8\%^*$	55% (53%, 56%), n = 6445	59% (56%, 61%), n = 1907	$\Delta = 4\%$	OR ^{$\times\times$} = 1.18 (0.92, 1.51), P = 0.19
Mean deft among those with deft > 0	3.31 (3.11, 3.50), n = 273	4.69 (4.48, 4.90), n = 1575	$\Delta = 1.38^*$	4.49 (4.36, 4.61), n = 3499	4.75 (4.56, 4.95), n = 1106	$\Delta = 0.26$	RR ^{$\times\times\times$} = 1.34 (1.23, 1.46), P < 0.001*
Permanent teeth							
Mean DMFT	0.36 (0.31, 0.41), n = 590	0.12 (0.10, 0.14), n = 2740	$\Delta = -0.24^*$	0.18 (0.17, 0.20), n = 6373	0.17 (0.13, 0.20), n = 1874	$\Delta = -0.01$	RR ^{\times} = 0.70 (0.51, 0.95), P = 0.024*
Percentage with DMFT ≥ 1	20% (18%, 22%), n = 590	8% (7%, 9%), n = 2740	$\Delta = -12\%^*$	10% (10%, 11%), n = 6373	9% (8%, 11%), n = 1874	$\Delta = -1\%$	OR ^{$\times\times$} = 0.37 (0.28, 0.49), P < 0.001*
Mean DMFT among those with DMFT > 0	1.72 (1.63, 1.82), n = 104	1.51 (1.39, 1.63), n = 221	$\Delta = -0.21$	1.77 (1.68, 1.85), n = 656	1.81 (1.65, 1.96), n = 169	$\Delta = 0.04$	RR ^{$\times\times\times$} = 0.88 (0.77, 1.01), P = 0.062

*Statistically significant at P < 0.05.

Sample sizes (n's) in 2013/14 are based on those with complete data on deft and all covariates, to permit direct comparability with Table S2.

Denominators for permanent teeth metrics include those with at least one permanent tooth.

^a Interaction term from regression analysis, regressing outcome variable on year (2013/14 vs 2004/05), city (Calgary vs Edmonton), age, and year \times city interaction (\times = zero-inflated Poisson regression; $\times\times$ = logistic regression; $\times\times\times$ = Poisson regression).

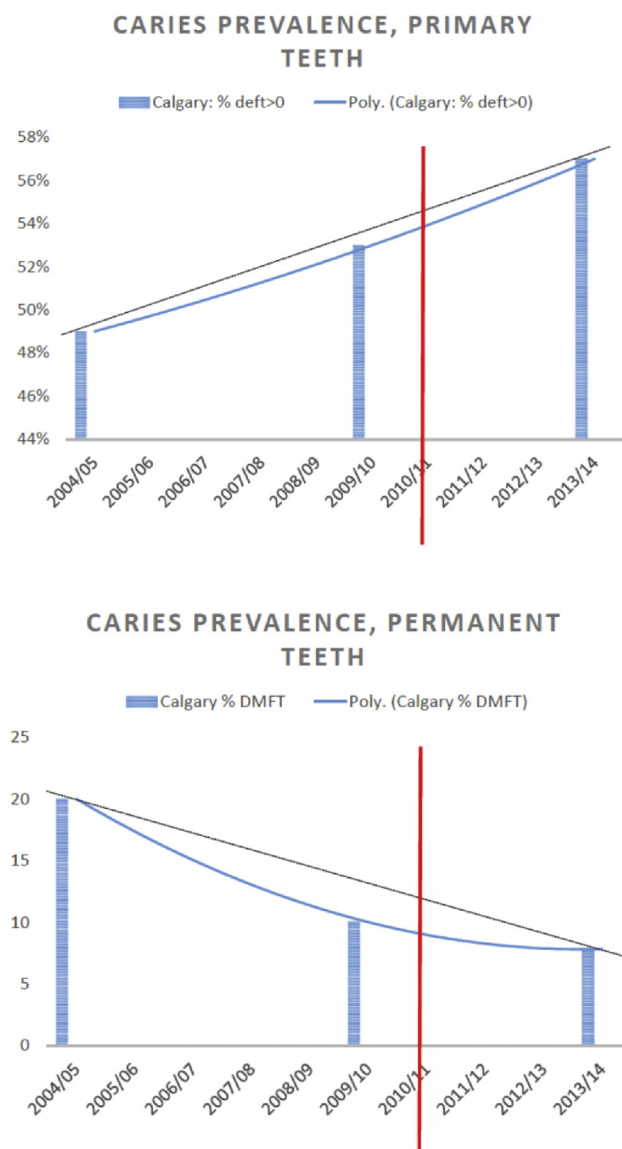


Fig. 1 – Prevalence of deft and DMFT in Calgary (cessation community) based on weighted survey estimates from 2004/05, 2009/10, and 2013/14.

place, and during that time frame, it was less consistent and smaller in magnitude.

The observed effect in primary tooth caries was consistent across our data. First, the 2013/14 estimates were robust to adjustment for differences between the samples in socio-demographic and behavioral variables. Second, the effect was consistent with estimates of total fluoride intake from fingernail clippings from a subsample, and municipal water quality reports, both of which confirmed less fluoride in Calgary than in Edmonton in 2013/14. Third, the effect occurred despite indications that treatment was higher in Calgary than in Edmonton. Although we were not able to measure treatment access directly, our observations that the proportion with ‘complete caries care’ increased over time in Calgary (decreased in Edmonton) suggest that children in Calgary are visiting the dentist more which, in addition to treatment, could also signal more preventive activities such as fluoride

application and uptake of dental hygiene recommendations. This possibility is supported by 2013/14 questionnaire data showing more frequent visits to the dentist, receipt of supplemental fluoride at the dentist, and more regular tooth brushing in Calgary than in Edmonton (Table S1).

We did not observe the same effect in permanent teeth, however, due to differences in the enamel of primary vs permanent teeth (i.e. primary teeth have thinner enamel and lower mineralization levels), primary teeth are likely more susceptible to demineralization and caries formation.^{39,40} It would thus be expected that we could see an impact on primary teeth sooner than in permanent teeth. Elsewhere,³⁸ we report a small and statistically non-significant increase in tooth decay amongst permanent teeth in Calgary, when looking specifically at smooth surfaces, which may indicate an early hint of an adverse effect.

Furthermore, when we considered the three data points available in Calgary only (2004/05, 2009/10, and 2013/14), there was some indication (though very small) that the worsening in primary tooth decay sped up, and the improvement in permanent tooth decay slowed down, in the latter period (2009/10–2013/14) compared with the former period (2004/05–2009/10), which is consistent with an adverse effect of fluoridation cessation on dental caries. For deft, that small descriptive trend was borne out for prevalence but not mean deft, which could reflect that the impact of a population-level measure such as community water fluoridation appears first on population-level metrics such as prevalence, rather than mean values which are influenced by children with more severe dental problems. However, comparison across the three data points in Calgary must be undertaken with caution, first, because there was only one school in common across the three data points (vs 11 in common between 2004/05 and 2013/14); and second, because in the absence of a 2009/10 data point for Edmonton, it is difficult to draw conclusions, other than that there are factors aside from fluoridation cessation that are contributing to trends observed. The comparative aspect of our study (2004/05–2013/14 in Calgary and Edmonton), and the single group descriptive trends (2004/05, 2009/10, and 2013/14 in Calgary only) appear to contribute different kinds of information (i.e. between- vs within-city change) to our question about fluoridation cessation and children’s oral health. Continued monitoring is important.

The study has several important limitations. First, our study design makes it difficult to rule out all potential confounders, particularly because our comparative analysis relies on a pre cessation data point that is several years before cessation. However, we emphasize that many published cessation studies do not include a comparison community;¹⁵ thus our study builds on some existing work in that regard local demand for this knowledge prompts use of the best available data.

Other limitations include the absence of questionnaire data from 2004/05, which meant that we could not compute adjusted estimates for the pre cessation period. The sample size for Calgary in 2004/05 ($n = 599$) was much smaller than for the other surveys. However, effects were robust to the application of sampling weights and to the wider the CI that accompanies a smaller and less precise estimate. The 2004/05

Table 2 – Percentages (weighted estimates) within different treatment level categories, grade 2 students in Calgary and Edmonton, 2004/05 and 2013/14.

Treatment level category	Calgary 2004/05	Calgary 2013/14	Calgary Δ	Edmonton 2004/05	Edmonton 2013/14	Edmonton Δ
	Percentage (95% CI)	Percentage (95% CI)		Percentage (95% CI)	Percentage (95% CI)	
No decay experience	46% (41%, 51%)	42% (40%, 43%)	$\Delta = -4\%$	44% (42%, 45%)	40% (37%, 43%)	$\Delta = -4\%$
Complete caries care	21% (18%, 24%)	34% (32%, 36%)	$\Delta = 13\%^*$	35% (33%, 36%)	29% (27%, 31%)	$\Delta = -6\%^*$
Partial caries care	19% (16%, 21%)	16% (14%, 17%)	$\Delta = -3\%$	13% (12%, 14%)	17% (15%, 20%)	$\Delta = 4\%^*$
No caries care	14% (12%, 17%)	9% (8%, 10%)	$\Delta = -5\%^*$	9% (8%, 10%)	13% (12%, 15%)	$\Delta = 4\%^*$
Total sample size	n = 590	n = 3182		n = 6373	n = 2263	

No decay experience: no decay, no extractions, no fillings.

Complete caries care: no decay, one or more instance of extraction or filling.

Partial caries care: one or more instance of decay; one or more instance of extraction or filling.

No caries care: one or more instance of decay; no extractions or fillings.

*Statistically significant difference between 2004/05 and 2013/14 at $P < 0.05$.

estimate for primary tooth caries was lower in Calgary (mean deft 1.62) than in Edmonton (mean deft 2.45), whereas for some permanent tooth caries measures the pattern was opposite. Because of rigorous sampling and assessment methods, coupled with our use of sampling weights, we have no reason to believe that the baseline estimates are inaccurate. A final important limitation is that, although assessment teams underwent extensive training and calibration, we did not collect data on inter-examiner or intra-examiner reliability.

Strengths of our study include high-quality oral health data gathered by trained and calibrated dental health professionals, population-based samples of schoolchildren and corresponding sampling weights, a comparative study design, incorporation of questionnaire data to capture important covariate information post cessation, and the collection of biomarker data from a subsample to permit corroboration of findings.

In summary, trends observed in caries rates in Calgary, Canada (especially in primary teeth), along with other information gathered, appear to be broadly consistent with an adverse effect of CWF cessation. It is important to undertake subsequent oral health surveys to monitor and confirm these trends over time.

Author statements

Acknowledgments

The authors thank Dr. Steven Levy, Dr. Eugenio Beltran, Dr. Kathy Phipps, Dr. Barry Maze, Dr. Gary Whitford, Ms. Jodi Siever, Ms. Vicki Stagg, Ms. Leanne Rodine, Ms. Joanna Czar-nobaj, Dr. Marianne Howell, Ms. Congshi Shi, Mr. Peter Peller, the dental hygienists and clerks who worked on the project, and the participating school boards, schools, and families.

Ethical approval

The study received approval from the Conjoint Health Research Ethics Board at the University of Calgary (ID E-25219) and the Health Research Ethics Board at the University of Alberta (ID Pro00037808).

Funding

The authors gratefully acknowledge funding support for this project from the Canadian Institutes of Health Research (funding reference GIR 127083), Alberta Health, and Alberta Health Services.

Lindsay McLaren holds an Applied Public Health Chair award funded by the Canadian Institutes of Health Research (Institute of Population and Public Health, Institute of Musculoskeletal Health and Arthritis), the Public Health Agency of Canada, and Alberta Innovates—Health Solutions.

Competing interests

None declared.

REFERENCES

1. Health Canada. *Report on the findings of the oral health component of the Canadian health measures survey, 2007–2009*. Ottawa, ON: Minister of Health; 2010.
2. Dye BA, Li X, Beltrán-Aguilar ED. *Selected oral health indicators in the United States, 2005–2008*. U.S. Dept Health Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics (NCHS); May 2012. NCHS Data Brief, No. 96.
3. Kamel MS, Thomson WM, Drummond BK. Fluoridation and dental caries severity in young children treated under general anaesthesia: an analysis of treatment records in a 10-year case series. *Community Dent Health* 2013;30:15–8.
4. Kumar JV, Adekugbe O, Melnik TA. Geographic variation in Medicaid claims for dental procedures in New York State: role of fluoridation under contemporary conditions. *Public Health Rep* 2010;125:647–54.
5. Canadian Institutes of Health Information (CIHI). *Treatment of preventable dental cavities in preschoolers: a focus on day surgery under general anaesthesia*. Ottawa: CIHI; 2013.
6. Canadian Academy of Health Sciences (CAHS). *Improving access to oral health care for vulnerable people living in Canada*. Ottawa: Canadian Academy of Health Sciences; 2014.
7. Ravaghi V, Quiñonez C, Allison PJ. Comparing inequalities in oral and general health: findings of the Canadian Health Measures Survey. *Can J Public Health* 2013;104(7):e466–71.
8. Jackson SL, Vann Jr WF, Kotch JB, Pahel BT, Lee JY. Impact of poor oral health on children's school attendance and performance. *Am J Public Health* 2011;101:1900–6.

9. Burt BA, Eklund SA. *Dentistry, dental practice, and the community*. 5th ed. Philadelphia, PA: W.B. Saunders Col; 1999.
10. Brown HK, McLaren HR, Josie GH, Stewart BJ. The Brantford–Sarnia–Stratford fluoridation caries study 1955 report. *Can J Public Health* 1956;47:149–59.
11. Burt BA. Prevention policies in light of the changed distribution of dental caries. *Acta Odontol Scand* 1998;56:179–86.
12. Burt BA. Concepts of risk in dental public health. *Community Dent Oral Epidemiol* 2005;33:240–7.
13. McDonagh M, Whiting P, Bradley M, Cooper J, Sutton A, Chestnutt I, et al. *A systematic review of public water fluoridation*. York: NHS Centre for Reviews and Dissemination. University of York; 2000 (Report 18). [shorter version published in *BMJ* 2000;321:855–9].
14. Iheozor-Ejiofor Z, Worthington HV, Walsh T, O'Malley L, Clarkson JE, Macey R, et al. Water fluoridation for the prevention of dental caries. *Cochrane Libr* 2015;(6).
15. McLaren L, Singhal S. Does cessation of community water fluoridation lead to an increase in tooth decay? A systematic review of published studies. *J Epidemiol Community Health* 2016;70(9):934–40.
16. Attwood D, Blinkhorn AS. Trends in dental health of ten-year-old school children in south-west Scotland after cessation of water fluoridation. *Lancet* 1988;2(8605):266–7.
17. Hulse G, Kenrick A, Thomas CH, Thomas A, Davies DJ, Lennon MA. Welsh water should reinstate fluoridation on Anglesey. *Br Dent J* 1995;178(2):46–7.
18. Journal of the Canadian Dental Association (JCDA). Understanding public decision-making on community water fluoridation. *J Can Dent Assoc* 2013;79:d77.
19. McLaren L, McIntyre L. *Drinking water fluoridation in Canada: review and synthesis of published literature*. Report prepared for the Public Health Agency of Canada; April 2011.
20. Potestio ML, McNeil DA, van der Lee G, McLaren L, Musto R, Shwart L. Community water fluoridation: factors that influence decision-makers in Alberta. (Unpublished results).
21. Statistics Canada. *Age group of child (13), census family structure (7) and sex (3) for the children in census families in private households of Canada, provinces, territories, census metropolitan areas and census agglomerations, 2006 and 2011 Censuses (table)*. 2012. “2011 Census of Canada: Topic-based tabulations.” Statistics Canada Catalogue no. 98-312-XCB2011023. Ottawa, Ontario. September 19, <http://www12.statcan.gc.ca/census-recensement/2011/dp-pd/tbt-tt/Ap-eng.cfm?LANG=E&APATH=3&DETAIL=0&DIM=0&FL=A&FREE=0&GC=0&GID=0&GK=0&GRP=1&PID=102073&PRID=0&PTYPE=101955&S=0&SHOWALL=0&SUB=0&Temporal=2011&THEME=89&VID=0&VNAMEE=&VNAMEF> (accessed 29 November 2016).
22. Statistics Canada. *Detailed language spoken most often at home (232), detailed other languages spoken regularly at home (233), age groups (17A) and sex (3) for the population excluding institutional residents of Canada, provinces, territories, census metropolitan areas and census agglomerations, 2011 census (table)*. 2012. “2011 Census of Canada: Topic-based tabulations.” Statistics Canada Catalogue no. 98-314-XCB2011042. Ottawa, Ontario, October 24, <http://www12.statcan.gc.ca/census-recensement/2011/dp-pd/tbt-tt/Ap-eng.cfm?LANG=E&APATH=3&DETAIL=0&DIM=0&FL=A&FREE=0&GC=0&GK=0&GRP=1&PID=103089&PRID=0&PTYPE=101955&S=0&SHOWALL=0&SUB=0&Temporal=2011&THEME=90&VID=0&VNAMEE=&VNAMEF> (accessed 29 November 2016).
23. Statistics Canada. *National household survey (NHS) and 2006 census long-form response rates*. Ottawa, Canada: Statistics Canada; 2011. http://www12.statcan.gc.ca/census-recensement/fc-rf/reports-rapports/r2_table-tableau_3-eng.cfm (accessed 29 November 2016).
24. Statistics Canada. *National Household Survey (NHS) 2011, individuals file*. 2014 (subset compiled from public use microdata file). Statistics Canada (producer). Using University of Toronto SDA (distributor), <http://sda.chass.utoronto.ca/sdaweb/html/nhspumf.htm> (accessed 29 November 2016). All computations, use and interpretation of these data are entirely those of the author.
25. Statistics Canada. *National Household Survey (NHS) 2011, hierarchical file*. 2014 (subset compiled from public use microdata file). Statistics Canada (producer). Using University of Calgary, spatial and Numeric data services (distributor).
26. Statistics Canada. *Mobility status 5 years ago (9), mother tongue (8), legal marital status (6), common-law status (3), age groups (16) and sex (3) for the population aged 5 years and over in private households of Canada, provinces, territories, census metropolitan areas and census agglomerations, 2011 national household survey (table)*. 2013. “2011 National Household Survey: Data tables.” Statistics Canada Catalogue no. 99-013-X2011026. Ottawa, Ontario, June 26, <http://www12.statcan.gc.ca/nhs-enm/2011/dp-pd/dt-td/Ap-eng.cfm?LANG=E&APATH=3&DETAIL=0&DIM=0&FL=A&FREE=0&GC=0&GID=0&GK=0&GRP=0&PID=105554&PRID=0&PTYPE=105277&S=0&SHOWALL=0&SUB=0&Temporal=2013&THEME=97&VID=0&VNAMEE=&VNAMEF> (accessed 29 November 2016).
27. Government of Alberta. Ministry of education. Edmonton, Canada: Government of Alberta. <https://education.alberta.ca/topic-search/?journeyId=1090&resetFilter=1> (accessed 29 November 2016).
28. Calgary Health Region. *Children's oral health survey report, 2004–2005*. *Calg Community Oral Health* 2008.
29. Shwart L, Rodine L. *Children's oral health survey, 2009–10*. Calgary: Alberta Health Services; 2010.
30. McLaren L, McNeil D, Potestio M, Patterson S, Thawer S, Faris P, et al. Equity in children's dental caries before and after cessation of community water fluoridation: differential impact by dental insurance status and geographic material deprivation. *Int J Equity Health* 2016;15:24.
31. Little RJA, Rubin DB. *Statistical analysis with missing data*. New York: John Wiley & Sons; 1987.
32. World Health Organization (WHO). *Oral health surveys: basic methods*. 5th ed. Geneva: World Health Organization; 2013.
33. Warren JJ, Levy SA, Kanellis MJ. Dental caries in the primary dentition: assessing prevalence of cavitated and noncavitated lesions. *J Public Health Dent* 2002;62(2):109–41.
34. Statistics Canada. *Canadian health measures survey, cycle 1*. Ottawa, Canada: Statistics Canada. http://www23.statcan.gc.ca/imdb-bmdi/document/5071_D2_T1_V1-eng.htm (accessed 29 November 2016).
35. Centers for Disease Control and Prevention. Division of oral health. Open data tools. Atlanta, Georgia: CDC. http://www.cdc.gov/oralhealth/data_systems/index.htm (accessed 29 November 2016).
36. Whitford GM, Sampaio FC, Arneberg P, von der Fehr FR. *Fingernail fluoride: a method for monitoring fluoride exposure*. *Caries Res* 1999;33:462–7.
37. Pessan JP, Buzalaf MAR. Historical and recent biological markers of exposure to fluoride. *Monogr Oral Sci* 2011;22:52–65.
38. McLaren L, Patterson S, Thawer S, Faris P, McNeil D, Potestio M, et al. Measuring the short-term impact of fluoridation cessation on dental caries in Grade 2 children using tooth surface indices. *Community Dent Oral Epidemiol* 2016 Jun;44(3):274–82.
39. Wang LJ, Tang R, Bonstein T, Bush P, Nancollas GH. Enamel demineralization in primary and permanent teeth. *J Dent Res* 2006;85(4):359–63.
40. de Menezes Oliveira MA, Torres CP, Gomes-Silva JM, Chinellatti MA, De Menezes FC, Palma-Dibb RG, et al. Microstructure and mineral composition of dental enamel of permanent and deciduous teeth. *Microsc Res Tech* 2010;73(5):572–7.

Appendix A

Fluoride content of municipal drinking water for two major water treatment plants in Calgary and Edmonton, 2005–2013.

Year	Fluoride content of municipal drinking water Calgary (F-cess) ^a		Fluoride content of municipal drinking water Edmonton (F-cont)	
	Bearspaw treatment plant: Range (mg/L)	Glenmore treatment plant: Range (mg/L)	Rossdale treatment plant: Range (mg/L)	E.L. Smith treatment plant: Range (mg/L)
2005	0.62–0.80	0.65–0.80	0.66–0.95	0.73–0.91
2006	0.66–0.72	0.59–0.77	0.76–0.85	0.73–0.88
2007	0.63–0.74	0.69–0.73	0.07–0.88 (avg 0.71, median 0.79) ^b	
2008	0.67–0.73	0.61–0.74	0.10–0.88 ^c	0.02–0.82 ^b
			Overall for both plants: avg = 0.58, median = 0.75	
2009	0.66–0.74	0.64–0.80	0.65–0.86	0.67–0.82
2010	0.66–0.73	0.64–0.89	0.62–0.77	0.65–0.75
2011	0.07–0.69*	0.08–0.74*	0.63–0.76	0.09–0.78 ^d
				(overall for both plants: avg = 0.65, median = 0.69)
2012	0.07–0.13	0.16–0.30	0.04–0.79 ^e (avg 0.73, median 0.68)	0.60–0.77
2013	0.07–0.16	0.11–0.28	0.62–0.78	0.61–0.82

* City of Calgary fluoridation ceased May 2011, as per approval amendment 476-02-01

^a F content of untreated water in Calgary 2005-2013 range: 0.06 to 0.21 (Bearspaw), 0.15 to 0.34 (Glenmore).

^b Note: As of Sept 26 2007 the fluoride lower limit was relaxed due to chemical supply shortages and construction at the E.L. Smith plant (approved by Alberta Environment). The shortage was relieved and construction was completed by July 08 and fluoride levels returned to normal.

^c no note, but average for Rossdale for 2008 is 0.78 mg/L.

^d Note: Fluoride was not added E. L. Smith WTP between Sept 8 and Oct 21 due to construction work on fluoride system.

^e Note: Fluoride was not added to Rossdale WTP between July 22 and Nov 29 due to construction work on fluoride system.

Appendix B. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.puhe.2016.12.040>.