

# Measuring the short-term impact of fluoridation cessation on dental caries in Grade 2 children using tooth surface indices

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**Abstract – Objectives:** To examine the short-term impact of fluoridation cessation on children's caries experience measured by tooth surfaces. If there is an adverse short-term effect of cessation, it should be apparent when we focus on smooth tooth surfaces, where fluoride is most likely to have an impact for the age group and time frame considered in this study. **Methods:** We examined data from population-based samples of school children (Grade 2) in two similar cities in the province of Alberta, Canada: Calgary, where cessation occurred in May 2011 and Edmonton where fluoridation remains in place. We analysed change over time (2004/2005 to 2013/2014) in summary data for primary (defs) and permanent (DMFS) teeth for Calgary and Edmonton, for all tooth surfaces and smooth surfaces only. We also considered, for 2013/2014 only, the exposed subsample defined as lifelong residents who reported usually drinking tap water. **Results:** We observed, across the full sample, an increase in primary tooth decay (mean defs – all surfaces and smooth surfaces) in both cities, but the magnitude of the increase was greater in Calgary (F-cessation) than in Edmonton (F-continued). For permanent tooth decay, when focusing on smooth surfaces among those affected (those with DMFS>0), we observed a non-significant trend towards an increase in Calgary (F-cessation) that was not apparent in Edmonton (F-continued). **Conclusions:** Trends observed for primary teeth were consistent with an adverse effect of fluoridation cessation on children's tooth decay, 2.5–3 years post-cessation. Trends for permanent teeth hinted at early indication of an adverse effect. It is important that future data collection efforts in the two cities be undertaken, to permit continued monitoring of these trends.

Key words: fluoridation; Public health

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Since its initial implementation in 1945, much research has been conducted on community water fluoridation (CWF) and its impact on dental caries.

Mechanistically, fluoride benefits teeth by inhibiting tooth demineralization, enhancing re-mineralization, and inhibiting enzyme activity of plaque bacteria<sup>1</sup>.

While both a systemic (pre-eruptive) and a topical (post-eruptive) mechanism of impact have been studied intensively, experts now seem to agree that fluoride's major anti-cariogenic effect is post-eruptive<sup>1,2</sup>; however, studies have continued to accrue that are consistent with some pre-eruptive effect<sup>3</sup>.

As a whole, the evidence base supports the benefits of fluoridation for preventing caries in populations<sup>4,5</sup>. However, systematic reviews have highlighted methodological limitations of the evidence base, such as weak study designs<sup>4,5</sup>. This reflects that research on CWF and CWF cessation is observational (takes advantage of natural experiment circumstances) and may rely on pre-existing data collected for another purpose. Contemporary evidence was furthermore noted to be sparse: in a recent systematic review<sup>5</sup>, 71% of included studies were conducted prior to 1975.

To a large extent, the research literature is characterized by studies of fluoridation initiation, early in the intervention's history<sup>6,7</sup> and cross-sectional comparisons of fluoridated and non-fluoridated communities<sup>8-10</sup>. There is less research on fluoridation cessation circumstances<sup>11</sup>, even though cessation appears to be occurring with increasing frequency in some regions. For example, in Canada alone since 2005, more than 30 communities have opted to discontinue fluoridation<sup>12</sup>. To inform fluoridation decision-making, high-quality research on the impact of cessation is needed. In our context, there was demand from decision-makers for high-quality, locally relevant evidence on the impact of fluoridation cessation on dental caries experience.

A systematic review (L. McLaren and S. Singhal, unpublished results) identified 15 instances of published research on fluoridation cessation in 13 countries. Those studies provided important insight into the impact of cessation on dental caries in different contexts. However, many of the studies had important methodological limitations, such as no comparison community<sup>13</sup> or no questionnaire data to assess important covariates<sup>14</sup>. Furthermore, many of the cessation studies were older: of the 15 jurisdictions represented in the review, only six focused on cessation that occurred in 1990 or later<sup>3,13,15-18</sup> and only one<sup>3</sup> since 2000. Older studies may not reflect contemporary circumstances such as historically low caries rates, skewed caries distributions (smaller proportion of people accounting for the majority of problems) and multiple sources of exposure to fluoride<sup>19</sup>. Finally, with important exceptions<sup>16</sup>, many studies examined the impact of cessation using tooth-level data.

Tooth surface-level data would be preferable, if the aim is to evaluate a prevention initiative<sup>20</sup> such as community water fluoridation or its cessation.

The purpose of this study was to examine the impact of fluoridation cessation on children's dental caries. Our analysis took advantage of the natural experiment opportunity provided by fluoridation cessation in the city of Calgary, Canada, which occurred in May 2011 (after having been in place since 1991). Published definitions of intervention in the research context highlight 'intentional change'<sup>21</sup> and 'to disturb the 'natural' order of things'<sup>22</sup>, and thus accommodate cessation (as well as initiation) of CWF as a viable study focus. We compared caries rates in Calgary to those in the city of Edmonton, where fluoridation began in 1967 and remains in place. Elsewhere (L. McLaren, S. Patterson, S. Thawer, P. Faris, D. McNeil, M. Potestio et al., unpublished results) we reported on tooth-level data and showed that for primary (but not permanent) teeth, a significant increase in caries between pre- and post-cessation was observed in Calgary (F-cessation). The effect was smaller and less consistent in Edmonton (F-continued). These initial findings for primary teeth were consistent with a short-term adverse effect of cessation on caries experience.

The objective of this article was to report further on the impact of CWF cessation on children's caries experience, focusing on smooth tooth surfaces, where fluoride is most likely to have an impact<sup>23</sup> for the age group and time frame considered in this study. If there is an adverse effect of fluoridation cessation, as observed in our other paper, it should be apparent using this more sensitive measure.

## Materials and methods

### *Design*

We used a pre-post cross-sectional design with comparison group. Data were collected from population-based samples of schoolchildren during the 2004/2005 and 2013/2014 school years (October-May/June). The target population was children in grade 2 attending school in the Public or Catholic school system in Calgary and Edmonton. Calgary and Edmonton are well matched: they are the two largest cities in the province of Alberta and are both large urban centres with diverse demographic profiles. We ascertained fluoride content of municipal drinking water in the two cities by securing annual water quality reports (L. McLaren,

S. Patterson, S. Thawer, P. Faris, D. McNeil, M. Potestio et al., unpublished results).

#### *Pre-cessation data (2004/2005)*

Pre-cessation data for Calgary and Edmonton were available from population-based surveys conducted by former health regions in Alberta in 2004/2005. Oral health data were collected via open mouth examinations conducted in the schools by trained and calibrated assessment teams, each consisting of a registered dental hygienist and a clerk. Decayed, missing/extracted, and filled teeth and surfaces were recorded using standard criteria<sup>20</sup>. Decay referred to cavitated decay, defined as a lesion that 'has a detectably softened floor, undermined enamel or softened wall. On interproximal surfaces, the point of the explorer must enter a lesion with certainty'<sup>24</sup>.

For Calgary in 2004/2005, a stratified random sample was selected, with strata based on median neighbourhood income quartile where the school was located. Within sampled schools, all children of eligible grades were invited to participate. An opt-in consent process was used, and the participation rate was 60%<sup>24</sup>. In Edmonton in 2004/2005, all elementary schools in the two school boards were invited to participate, and within each school, a sample was taken from each class with the sample size predetermined based on class size (80–100% of the full class). The participation rate was approximately 89%.

#### *Post-cessation data (2013/2014)*

Data collection in 2013/2014 was designed to maximize comparability with the 2004/2005 surveys. We drew a stratified random sample, with strata based on the median neighbourhood income quartile where the school was located. Trained and calibrated assessment teams, each consisting of a registered dental hygienist and a clerk, conducted open mouth examinations following the protocol from the Iowa Fluoride Study<sup>25</sup>, which is based on the WHO criteria<sup>20</sup> and yields a  $d_{1d_{2-3}mf}$  index based on whole tooth codes and 2-digit surface-specific codes. Our analysis focused on  $d_{2-3}$  to permit comparability with the decay data in the 2004–05 surveys. Assessments were based on all primary teeth and a subset of 12 permanent teeth (central incisors, lateral incisors and 1st molars). The same 12 permanent teeth were considered pre- and post-cessation. Assessment teams were trained together in the protocol, and each team was calibrated on two occasions (early October and mid-

November 2013) by a public health dentist with considerable experience in survey calibration and an extensive knowledge and background in survey methodology and tooth surface-level assessment. Signed parental consent and child verbal assent were secured for the open mouth examination. Post-cessation data collection also included a parent questionnaire and, for a small random subsample in each city, fingernail clippings to assess total fluoride intake (L. McLaren, S. Patterson, S. Thawer, P. Faris, D. McNeil, M. Potestio et al., unpublished results). The 2013/2014 school-level participation rates were 57.3% (Calgary) and 54.1% (Edmonton), and the student-level participation rate within participating schools were 49.1% (Calgary) and 47.0% (Edmonton).

#### *Variables and data analysis*

In this article, we focused on summary data for tooth surfaces, both primary (defs) and permanent (DMFS). Because both defs and DMFS tended to be positively skewed, we examined both overall mean and the mean for those with one or more defs or DMFS. We considered all tooth surfaces, as well as smooth surfaces only. Our designation of smooth surfaces included all surfaces *except* the following: occlusal surfaces (whenever present), and surfaces where pit and fissure caries commonly occur, namely buccal (vestibular) surfaces for teeth 46 and 36, and lingual surfaces for teeth 16 and 26 (Though we had codes to specifically indicate pit and fissure caries in the 2013/2014 data, we used the proxy approach of excluding certain surfaces to permit comparability with 2004/2005 (for which we did not have that specific information). When we computed smooth surface caries summary measures in 2013/2014 using the specific pit and fissure designation, the estimates tended to be higher (for example, in Table 1b, mean DMFS among those with DMFS>0 was 2.3 [versus 2.0] for Calgary and 2.1 [versus 1.7] for Edmonton).).

Permanent tooth summary data (DMFS) were based on children with at least one permanent tooth. The percentage of children with at least one permanent tooth, and the mean number of permanent teeth, did not differ appreciably across surveys: the percentages with zero permanent teeth were 1.5% (Calgary 2004/2005), 1.1% (Edmonton 2004/2005), 1.5% (Calgary 2013/2014) and 1.9% (Edmonton 2013/2014), and the mean numbers of permanent teeth, of the 12 assessed, were 9.1 (Calgary 2004/2005), 9.0 (Edmonton 2004/2005), 8.8 (Calgary 2013/2014) and 8.7 (Edmonton 2013/

Table 1. Dental caries summary measures in Calgary and Edmonton, 2004/2005 and 2013/2014, Grade 2 students. Weighted estimates. Full sample

	Calgary 2004/2005	Calgary 2013/2014	Calgary change (2013/2014 – 2004/2005)	Edmonton 2004/5	Edmonton 2013/4	Edmonton change (2013/2014 – 2004/2005)	Year x city interaction term: Rate ratio and 95% confidence interval from Poisson regression
a) All tooth surfaces							
Mean defs	2.6 (2.2–3.0) <i>n</i> = 599	6.4 (5.9–6.9) <i>n</i> = 3230	3.8 <sup>a</sup>	4.5 (4.1–4.8) <i>n</i> = 6445	6.6 (6.0–7.2) <i>n</i> = 2307	2.1 <sup>a</sup>	1.6 (1.4–1.8), <i>P</i> < 0.01 <sup>c</sup>
Mean defs among those with defs>0	5.4 (5.0–5.7) <i>n</i> = 273	11.3 (10.6–12.0) <i>n</i> = 1835	5.9 <sup>a</sup>	8.3 (7.8–8.8) <i>n</i> = 3415	11.2 (10.5–11.9) <i>n</i> = 1334	2.9 <sup>a</sup>	1.6 (1.4–1.8), <i>P</i> < 0.01
Mean DMFS	0.45 (0.37–0.52) <i>n</i> = 590	0.15 (0.13–0.17) <i>n</i> = 3182	-0.3 <sup>a</sup>	0.25 (0.22–0.28) <i>n</i> = 6373	0.21 (0.17–0.25) <i>n</i> = 2263	-0.04	0.8 (0.6–1.1), <i>P</i> = 0.3 <sup>c</sup>
Mean DMFS among those with DMFS>0	2.2 (2.0–2.5) <i>n</i> = 99	2.0 (1.8–2.2) <i>n</i> = 253	-0.2	2.4 (2.2–2.6) <i>n</i> = 652	2.2 (2.0–2.4) <i>n</i> = 201	-0.2	0.96 (0.8–1.2), <i>P</i> = 0.6
b) Smooth surfaces only <sup>b</sup>							
Mean defs	1.4 (1.2–1.6) <i>n</i> = 599	4.3 (3.9–4.7) <i>n</i> = 3230	2.9 <sup>a</sup>	2.8 (2.5–3.0) <i>n</i> = 6445	4.4 (3.9–4.8) <i>n</i> = 2307	1.6 <sup>a</sup>	1.8 (1.6–2.2), <i>P</i> < 0.01 <sup>c</sup>
Mean defs among those with defs>0	3.3 (3.0–3.6) <i>n</i> = 236	8.6 (8.0–9.2) <i>n</i> = 1583	5.3 <sup>a</sup>	5.9 (5.4–6.4) <i>n</i> = 2999	8.9 (8.2–9.6) <i>n</i> = 1109	3.0 <sup>a</sup>	1.7 (1.5–2.0), <i>P</i> < 0.01
Mean DMFS	0.04 (0.00–0.07), <i>n</i> = 590	0.02 (0.01–0.03), <i>n</i> = 3182	-0.02	0.02 (0.01–0.02) <i>n</i> = 6373	0.02 (0.01–0.03) <i>n</i> = 2263	0.0	2.7 (1.0–7.4), <i>P</i> = 0.06 <sup>c</sup>
Mean DMFS among those with DMFS>0	1.7 (1.4–2.0) <i>n</i> = 12	2.0 (1.5–2.6) <i>n</i> = 40	0.3	1.7 (1.4–2.1) <i>n</i> = 59	1.7 (1.3–2.1) <i>n</i> = 28	0.0	1.2 (0.8–1.8), <i>P</i> = 0.3

defs = decayed, extracted (due to caries), filled primary tooth surfaces; DMFS = decayed, missing (due to caries), filled permanent tooth surfaces.

<sup>a</sup>Statistically significant difference between 2004/2005 and 2013/2014, based on non-overlapping 95% confidence intervals (CI).

<sup>b</sup>Omits occlusal surfaces whenever present; omits buccal (vestibular) surfaces for teeth 46 and 36; omits lingual surfaces for teeth 16 and 26.

<sup>c</sup>Interaction terms based on zero-inflated Poisson regression.

2014). The median (6) and range (0–12) were the same for all four survey samples.

For 2013/2014 only, we additionally considered the subsample of lifelong residents who reported usually drinking tap water (versus bottled water). This information was gleaned from the parent questionnaires included as part of the 2013/2014 data collection.

We examined change over time in Calgary (F-cessation) compared to change over time in Edmonton (F-continued). Change over time was inferred from non-overlapping 95% confidence intervals for means, which was then verified by testing a year x city interaction term in a Poisson regression.

All analyses applied sampling weights developed for this project, which accounted for the clustered sampling design and response imbalances. We also ran all analyses unweighted and results were broadly similar (no change to statistical significance). Weighted estimates are presented below.

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). Approval was also sought and granted by all four participating school boards.

## Results

Results for primary teeth were based on the following sample sizes:  $n = 599$  for Calgary 2004/2005;  $n = 6445$  for Edmonton 2004/2005;  $n = 3230$  for Calgary 2013/2014; and  $n = 2307$  for Edmonton

2013/2014. The sample sizes for permanent teeth were slightly smaller because the denominator included those with at least one permanent tooth. Sample sizes for the 2013/2014 subsample (lifelong residents who reported usually drinking tap water) were:  $n = 930$  and  $n = 916$  for Calgary defs and DMFS, respectively, and  $n = 575$  and  $n = 565$  for Edmonton defs and DMFS, respectively.

The summary data for Calgary and Edmonton, in 2004/2005 (pre-cessation) and 2013/2014 (post-cessation) are shown in Table 1. For primary teeth (defs), a statistically significant increase was apparent in both Calgary and Edmonton, although the absolute magnitude of the increase was greater in Calgary (F-cessation). This was true for all primary tooth surfaces (Table 1a) and for primary smooth surfaces only (Table 1b). In all cases (mean defs, mean defs among those with defs>0; all surfaces and smooth surfaces only), the greater increase in Calgary compared to Edmonton was confirmed in a Poisson regression that showed a statistically significant year x city interaction term (far right hand column in Table 1), indicating that the increase in primary tooth decay in Calgary (F-cessation) over time was significantly greater than that in Edmonton.

Table 1 also contains permanent tooth summary data (DMFS). For all tooth surfaces among permanent teeth (Table 1a), there was a statistically significant decrease in Calgary, for the overall mean DMFS, which was not observed in Edmonton. For permanent tooth smooth surfaces only (Table 1b), there was no statistically significant change over time in Calgary or Edmonton. However, we noted a trend (non-significant) towards an increase in

Table 2. Dental caries summary measures in Calgary and Edmonton, Grade 2 students, 2013/2014 only. Weighted estimates. Estimates are for the subsample of lifelong residents who reported usually drinking tap water

	Calgary 2013/2014 Mean (95% CI), $n$	Edmonton 2013/4 Mean (95% CI), $n$
a) All tooth surfaces		
Mean defs	5.2 (4.5–5.8), $n = 930$	5.5 (4.5–6.5), $n = 575$
Mean defs among those with defs>0	9.9 (8.9–11.0), $n = 477$	10.5 (9.0–12.0), $n = 289$
Mean DMFS	0.14 (0.09–0.18), $n = 916$	0.11 (0.07–0.16), $n = 565$
Mean DMFS among those with DMFS>0	2.0 (1.5–2.4), $n = 63$	1.8 (1.4–2.2), $n = 37$
b) Smooth surfaces only <sup>a</sup>		
Mean defs	3.3 (2.8–3.8), $n = 930$	3.6 (2.9–4.4), $n = 575$
Mean defs among those with defs>0	7.3 (6.4–8.3), $n = 409$	9.0 (7.5–10.4), $n = 225$
Mean DMFS	0.04 (0.01–0.07), $n = 916$	0.01 (0.00–0.02), $n = 565$
Mean DMFS among those with DMFS>0	3.0 (1.9–4.0), $n = 12$	1.0 (variance could not be computed), $n = 7$

defs = decayed, extracted (due to caries), filled primary tooth surfaces; DMFS = decayed, missing (due to caries), filled permanent tooth surfaces; 95% CI = 95% confidence interval.

<sup>a</sup>Omits occlusal surfaces whenever present; omits buccal (vestibular) surfaces for teeth 46 and 36; omits lingual surfaces for teeth 16 and 26.

permanent tooth smooth surface decay severity in Calgary, among those affected (mean DMFS among those with DMFS > 0 increased by 0.3 between 2004/2005 and 2013/2014). There were no statistically significant (at  $P < 0.05$ ) year  $\times$  city interaction terms for permanent teeth measures.

Table 2 shows summary data for 2013/2014, but this time estimates were restricted to the subsample of lifelong residents who reported usually drinking tap water. In general, the estimates for the subsample (Table 2) tended to be similar to or lower than for the full sample (Table 1) for both Calgary and Edmonton, with few exceptions (permanent tooth measures for smooth surfaces in Calgary). The 2013/2014 subsample estimates in Table 2 could not be compared directly to 2004/2005 data, due to lack of questionnaire data which with to define a comparable subsample in 2004/2005.

## Discussion

We set out to examine the short-term impact of fluoridation cessation on children's caries experience, with a specific interest in whether findings we observed based on tooth-level data (L. McLaren, S. Patterson, S. Thawer, P. Faris, D. McNeil, M. Potestio et al., unpublished results) – namely an adverse effect of cessation on caries experience for primary teeth – were also apparent when focusing on smooth tooth surfaces, where fluoride is most likely to have an impact<sup>23</sup> for the age group and limited period of time considered in this study. If an adverse effect of cessation is indeed occurring, it should be apparent when using this more sensitive measure.

This line of thinking was borne out in our results. In primary teeth, an increase in caries experience was observed in Calgary (where cessation occurred in 2011). A similar observation, which was smaller in magnitude, was noted in Edmonton (where fluoridation remained in place). Thus, for primary teeth, our results presented here and elsewhere (L. McLaren, S. Patterson, S. Thawer, P. Faris, D. McNeil, M. Potestio et al., unpublished results) provide consistent indication of an adverse short-term effect of cessation.

In permanent teeth, we elsewhere (L. McLaren, S. Patterson, S. Thawer, P. Faris, D. McNeil, M. Potestio et al., unpublished results) reported a decrease in caries over time in both Calgary (F-cessation) and Edmonton (F-continued), which was larger and more consistent in Calgary. Based on

knowledge of enamel differences between primary and permanent teeth<sup>26,27</sup>, which make it likely that effects of cessation would appear sooner in primary teeth, we suggested that the absence of an increase in permanent teeth may have reflected the short time frame since cessation in our study, and that continued monitoring would be important to see if an adverse effect in permanent teeth emerges as time passes.

In this study, though effects were not statistically significant, the decrease in permanent tooth decay in Calgary (F-cessation) that we observed using tooth-level data (L. McLaren, S. Patterson, S. Thawer, P. Faris, D. McNeil, M. Potestio et al., unpublished results) and for all tooth surfaces (this manuscript, Table 1a) was muted when we focused on smooth surfaces only; and for mean DMFS among those with DMFS>0, the direction of change became positive (though non-significant). Further, though estimates from the 2013/2014 subsample (lifelong residents who reported usually drinking tap water) are based on small numbers, they were nonetheless consistent with an apparent increase in Calgary (F-cessation), because the Calgary estimate of mean DMFS among those with DMFS>0 was even higher in the subsample (3.0) (that is, even more discrepant from the 2004/2005 estimate) than in the full sample (2.0). Though we do not know what the subsample estimates would have been for 2004/2005 due to lack of questionnaire data, we note that both residential mobility and bottled water consumption were lower in 2004/2005 than in 2013/2014. Specifically, net migration (inter- and intra-provincial) increased in Calgary from 14 099 in 2004/2005 to 16 781 in 2013/2014, and in Edmonton from 9548 in 2004/2005 to 17 482 in 2013/2014<sup>28</sup> (that is, the population in both cities was more stable, in terms of migration, in 2004/2005 than in 2013/2014), and statistics on bottled water sales for Canada showed an increase over time; for example, litres per household (total volume) increased from 104.5 in 2004 to 173.8 in 2014<sup>29</sup> (Data on bottled water sales or consumption for the specific parameters of Calgary, Edmonton, 2004/05 and 2013/14 could not be located.). Therefore, it seems reasonable to assert that the discrepancy between the estimates for the full sample and for the subsample would be larger in 2013/2014 than in 2004/2005; or in other words, it would make less difference to exclude non-lifelong residents and bottled water drinkers in 2004/2005 than in 2013/2014. However, we do not know this for certain.

Taken together, our findings were consistent with an adverse effect of fluoridation cessation on children's caries experience, about 2.5–3 years post-cessation. The effect was most apparent for primary teeth, but it appeared from these analyses that an effect for permanent teeth, which, initially, we hypothesized would take longer to occur (if it occurred at all), was emerging. If true, one might expect a statistically significant effect on permanent teeth to become evident at further follow-up as the permanent teeth in the age group studied have been present in the mouth for a longer period. As we reported elsewhere, findings were consistent with lower fluoride in Calgary than in Edmonton based on 1) annual estimates of fluoride in drinking water secured from each city and 2) estimates of total fluoride intake from biomarkers (fingernail clippings) from a subsample in each city. Furthermore, estimates were robust to adjustment for socio-demographic and behavioural/dental characteristics of the Calgary and Edmonton samples in 2013/2014 (L. McLaren, S. Patterson, S. Thawer, P. Faris, D. McNeil, M. Potestio et al., unpublished results).

Our findings contribute to the published literature on fluoridation cessation and impact on dental caries. While several studies showed an increase in caries following cessation of fluoridation<sup>17,30</sup>, several others did not<sup>31,32</sup>. Among the studies that did observe an increase in caries, several were many years or decades old<sup>33,34</sup>, and it is important to question whether an adverse effect of fluoridation cessation on caries experience is apparent contemporarily. Our results were somewhat different from the one other Canadian study<sup>16,35</sup> which, based on repeated cross-sectional data, did not observe an adverse trend in tooth decay in the cessation community, following cessation in 1992. However, that finding may have reflected changes over time in treatment and preventive practices such as an increase in application of protective sealants, and the importance of investigating smooth surfaces. Collectively, the literature (including our study) indicates that the impact of fluoridation cessation on dental caries is not uniformly positive or negative but varies by time and place, and sorting out the reasons for different patterns is important.

The increase in caries (especially in primary teeth) observed in both cities in our study, though consistent with anecdotal reports from those regions (personal communication, Associate Dental Public Health Officer, Alberta Health Services, 19 January 2015), contrasts with other reports of a

general decline in child caries prevalence during recent decades<sup>19,36</sup>. The reasons for the increase are not known but could have to do with various factors impacting the province or larger geographies. Some examples include the global economic recession of 2008 and its social and economic aftermath; shifts in the Alberta economy due to rising and falling prices in the province's primary industry of oil and gas, which have implications for employment and migration (workers coming to Alberta); increasing ethnic diversity in Canadian cities including Alberta (for example, the percent of the Alberta population who only speak a non-official language most often at home has shown an increasing trend, with 7.5%, 9.1% and 10.5% in the 2001, 2006 and 2011 census, respectively)<sup>37,38</sup>; and trends in bottled water consumption which, as noted above, has increased for Canada as a whole. Although data on trends in sugar consumption are not specifically available for our samples, national data suggest that that may not present a likely explanation: although the percentage of daily calories from sugar is higher among four- to eight-year olds (which contains the age group in our study) than among the population as a whole (26%, versus 21%)<sup>39</sup>, overall, sugar consumption has decreased for the Canadian population over time, including between 2004 and 2013<sup>40</sup>. The reasons for the increase in caries in our two cities is an important remaining question.

Limitations of our study included the short duration of follow-up since cessation, the absence of questionnaire data from 2004/2005, non-identical examination criteria at the two time points (although both were anchored in the WHO criteria and yielded comparable summary measures), the use of different (though highly-skilled) calibrators in 2004/2005 and 2013/2014 and lack of blinding of examiners to residence of participants. Our pre-cessation data (2004/2005) were collected several years prior to cessation (2011) and it would have been preferable to have data collected closer to the year of cessation. However, elsewhere (L. McLaren, S. Patterson, S. Thawer, P. Faris, D. McNeil, M. Potestio et al., unpublished results) we considered other possible explanations such as socio-demographic characteristics of the samples and dental treatment and preventive programming and concluded that they did not appear to represent likely alternative explanations for our findings. The greater increase over time in deciduous caries experience observed in Calgary reflects, in part, the low estimates in 2004/2005 (compared to Edmon-

ton). However, because of the rigorous sampling methods and development and application of sampling weights, we believe the 2004/2005 estimates to be an accurate reflection of the caries experience at that time. The differences between Calgary and Edmonton pre-cessation speak to the importance of using a study design that involves comparison of change over time when evaluating the impact of CWF cessation, versus a cross-sectional post-cessation study.

Strengths of our study include: high-quality oral health data gathered by trained and calibrated dental professionals; population-based samples coupled with development and application of sampling weights to maximize representativeness of each sample of its underlying population; a comparative study design that permitted analysis of change over time; and multiple sources of data (open mouth examination; biomarker data; questionnaire) which allowed for assessment of consistency of findings across multiple indicators.

In conclusion, findings observed for primary teeth were consistent with an adverse effect of fluoridation cessation on children's tooth decay, 2.5–3 years post-cessation. Trends for permanent teeth hinted at early indication of an adverse effect. It is important that future data collection efforts in the two cities be undertaken, to allow continued monitoring of these trends.

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