Impact of water fluoridation on dental caries decline across racial and income subgroups of Brazilian adolescents.

Water Fluoridation, inequalities and caries decline

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Statement of Ethics

This investigation complies with the guidelines for human studies and should include evidence that the research was conducted ethically following the World Medical Association Declaration of Helsinki. All subjects have given their written informed consent, and that the institute's committee approved the study protocol on human research. Ethical approval for the SB Brazil 2010 was granted by the Ethics Health Commission (CNS), Resolution (CNS) 15498, on July 1, 2010, and in 2003 resolution CNS 1.356, process 25.000.009.632/00-51 on July 21, 2000. All participants provided their informed consent.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

Author 1 RAB: Contributed to conception, design, data interpretation, performed all statistical analyses, drafted and critically revised the manuscript

Author 2 PF: Contributed to conception, design, data interpretation, drafted and critically revised the manuscript

All authors gave their final approval and agreed to be accountable for all aspects of the work.

More information could be seen at:

SBBrazil 2003:

https://bvsmis.saude.gov.br/bvs/publicacoes/condicoes_saude_bucal.pdf

SBBrazil 2010:

https://bvsmis.saude.gov.br/bvs/publicacoes/pesquisa_nacional_saude_bucal_sbbrasil_2010.pdf

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Impact of water fluoridation on dental caries decline across racial and income subgroups of Brazilian adolescents.

Abstract

Objective. To assess the impact of community water fluoridation (CWF) on differences in dental caries decline across racial and socioeconomic subgroups of Brazilian adolescents. **Methods.** Two nationwide Brazilian population-based oral health surveys were used (SBBrazil 2003-2010). Seven thousand one hundred ninety-eight adolescents from 15 to 19 years old living in fifty cities investigated in both surveys were included. Mean values of untreated decayed teeth (DT) according to racial (Whites versus Browns/Blacks) and socioeconomic subgroups (at or above one minimum wage per capita versus under) were analyzed. Difference-in-Differences negative binomial regressions were adjusted by schooling, age, and sex. Decayed, missing, and filled teeth (DMFT) and decayed teeth prevalence were used for sensitivity analysis. **Results.** The adjusted difference of reduction in DT was similar for socioeconomic subgroups [$\beta = -0.05$ (-0.45, 0.35)] and favoured but not to a significant degree the Whites [$\beta = -0.34$ (-0.74, 0.04)] compared to Brown/Blacks in the fluoridated area. Significant reduction differences were observed in decayed teeth favouring the higher socioeconomic subgroup [$\beta = -0.26$ (-0.53,-0.01)] and the Whites [$\beta = -0.40$ (-0.69,-0.11)] in relation to their counterparts in the non-fluoridated area. Sensitivity analysis confirmed the findings. **Conclusion.** A similar reduction in DT across income subgroups suggests the beneficial effect of CWF to tackle income inequalities in dental caries within a 7-year timeframe.

Keywords: Water fluoridation, racial inequalities, socioeconomic inequalities, dental caries, oral health, public health

Introduction

Dental caries is one of the most prevalent diseases globally. Untreated dental caries affects 35% of the worldwide population (2.4 billion people), with a greater impact on socioeconomically disadvantaged and vulnerable¹.

The preventive effects of conjoint exposure (e.g., use of fluoride toothpaste in a fluoridated area) are additive and lower than the sum of each one's effect². Moreover, **Community Water Fluoridation** (CWF) is associated with reduced dental ambulatory sensitive hospitalizations³, and its cessation increased decayed primary teeth⁴.

Although the information on the impact of water fluoridation on dental caries inequalities is insufficient⁵, some studies have shown that CWF has the potential to reduce race- and income-related inequalities⁶⁻⁸. For example, in Brazil, which has the world's largest population of African descent outside of the native continent, a study showed that CWF was associated with reduced ethnic inequalities in dental caries in deprived settings⁹.

The use of fluoride is a breakthrough in public health, and the 6017 resolution from World Health Assembly confirms the relevance of CWF policy for promoting oral health¹⁰. More than a political issue, CWF is an ethical issue¹¹. Communities that have ceased fluoridation showed increased values of dental caries in children^{4,12-13}. Australian children from 9 to 14 years old and 100% of lifetime exposure to fluoridated water had significantly less dental caries than those with lower exposure¹⁴. Comparing USA counties with distinct levels of water fluoridation coverage ($\geq 75\%$ versus $< 75\%$), researchers found a difference of 12% in dental caries experience in children and adolescents aged 6 to 17 years old¹⁵.

A randomized controlled trial is a study design essential for assessing clinical interventions; however, it is challenging to manage for evaluating the efficacy of

population-based public policies like water fluoridation. Therefore, other methods specifically designed for causal inference in observational data have been proposed for impact assessment¹⁶⁻¹⁷. In Brazil, the fluoridation of public water supplies is mandatory since 1974, according to Federal Law 6,050. However, it is estimated that 40% of the Brazilian cities are not provided by this beneficial public health policy¹⁸. Dental caries has been declining, and income inequalities persist in Brazil¹⁹. To the author's knowledge, no study compared decline differences across income and racial subgroups in two time-points according to fluoridated and non-fluoridated areas utilizing a Difference-in-Difference approach¹⁷. Although this design permits the investigation of a potential association between policy implementation and the measured outcome, the main focus was to verify whether the decline differed across racial and income subgroups.

The aim was to assess the impact of community water fluoridation on differences in dental caries decline across racial and socioeconomic subgroups of Brazilian adolescents between 2003 and 2010 in the context of widespread use of fluoride toothpaste.

Methods

Data came from the latest two nationwide population-based oral health surveys in 2003²⁰ and 2010²¹ (Brazilian Oral Health Survey - SBBrazil-2003 and PNSB-2010). In 2003, the survey was conducted in 250 municipalities and in 2010 in 177 municipalities. Probability cluster sampling was used for selecting children, adolescents, adults and elders. Only individuals from 15 to 19 years old living in cities investigated in both surveys were included in the analysis.

Both surveys' interviews and clinical examinations followed the same criteria recommended by WHO²² for dental caries measuring and were carried out in respondents' homes by teams consisting of a general dentist and an assistant. Handbooks were

particularly elaborated to guide the procedures of sampling and data collection at each survey. Depending on the field characteristics, two to five dental examiners were selected and underwent between 24 and 32 hours of training and calibration in each municipality alone or in group of two or three municipalities. Kappa values above 0.65 were considered acceptable in both surveys^{20,21}. Examiners with Kappa values above 0.65 were approved for data collection.

Ethical approvals for 2003 and 2010 oral health surveys were granted by the Research Ethics Commission of Brazilian Health Council respectively on July 21st, 2000 (Resolution CNS 1.356), and on July 1st, 2010 (Resolution CNS 15498). All participants provided their informed consent.

The outcome was the mean values of untreated decayed teeth (DT), defined as a count variable that estimates the participant's current disease severity. According to WHO criteria, DT was recorded where a lesion in the pit and fissure or on a smooth tooth surface had an unmistakable cavity, undermined enamel, or a detectably softened floor or wall; or where a temporary restoration (except glass ionomer) was present²². The CPI probe was used to confirm caries' visual evidence on the occlusal, buccal, and lingual surfaces. We considered the tooth and not the surface as the unit parameter.

The investigated intervention was the provision of CWF. Fifty Brazilian cities were investigated both at 2003 and 2010 oral health surveys, and twenty-five of them provided CWF since at least 2000. They were grouped into two different strata, the non-fluoridated and fluoridated areas. Information on CWF was obtained from two different data sources, based on the information provided by water companies and municipal water surveillance^{18,23-24}.

The effect of CWF was assessed according to different categories of racial and income subpopulations. The racial variable was based on the respondent's self-assessment considering categories used by the Brazilian Institute for Geography and Statistics, based on skin colour. The categories included Whites, Asians, Browns (mixed ethnicity), Blacks, and Indigenous groups²⁵. As proportions of adolescents belonging to Indigenous (0.8%) and Asian (1%) groups were very small in the two independent samples, they were not included in the final analysis. Income was measured using equivalised per capita monthly household income and dichotomized to distinguish between families living below the Brazilian minimum wage ($<1\text{MW}$) and those at or above minimum wage ($\geq 1\text{MW}$)²⁶. In December 2003, the Brazilian minimum wage was BRL 240 (Brazilian Reais) or 83,33USD (US Dollars). In December 2010, the Brazilian minimum wage was BRL 510.00 (Brazilian Reais) or USD 301.70 (US Dollars). Covariates were age in years, sex (male; female), and schooling (under and at or above four years) related to the adolescents. Descriptive analyses included cross-tabulations of the outcome for racial (Whites versus Browns/Blacks) and equalized income (under and at or above one MW) subgroups according to the CWF. Point estimates and 95% confidence intervals interpreted the outcome mean values. Both areas are experiencing declining trends of dental caries¹⁷. There was no change in the drinking water status during the study period. As the focus was to investigate reduction differences across racial and income subgroups, the fact of CWF intervention to have begun at least three years before the baseline data did not undermine the analysis herein undertaken.

We regressed DiD stratified by CWF exposure. In the stratum of the CWF area, the association between the outcome and categories of racial subgroups (Browns/Blacks versus Whites) and socioeconomic subgroups (lower versus upper income), with an interaction term, i.e., the year, was investigated. The same was done in the stratum of

non-fluoridated areas (control units). This analysis quantifies the reduction difference of the outcome between the years across racial and socioeconomic subgroups. Due to the overdispersion of the outcome values, coefficients across racial and socioeconomic subgroups were estimated using negative binomial regression. All analyses were adjusted by sex, age and schooling. Beta coefficient (β) was interpreted as the mean reduction of a group compared to its reference group (R) with a 95% confidence interval. Moreover, the percentage difference (% D) values resulting from the quotient between the β coefficient and the baseline mean of the reference group (R) were also reported²⁷.

Analyses were carried out using Stata Version 14.2 (College Station, TX, EUA). Sampling weights available in the database were employed. All analyses were based on complete cases (without missing values) in the independent samples. Analysis comparing the total sample with the analyzed samples showed no significant differences in any outcome or covariates. Sensitivity analysis stratifying DT's number as dichotomous (0- without caries and 1- $D \geq 1$) and using DMFT were done (supplementary material). We used the Strobe Guidelines to report the results of the present investigation.

Results

Seven thousand one hundred ninety-eight adolescents comprised the analytical sample. Table 1 shows the distribution of the sample's characteristics as a whole. At both 2003 and 2010, the 95% confidence intervals of the mean values of untreated decayed teeth were significantly higher in the non-fluoridated than fluoridated area, and mean decayed teeth was higher for the lower-income group. In addition, the mean value of DT was significantly higher for Browns/Blacks than Whites in 2010.

Adolescents self-declared Browns/Blacks had higher DT value than their counterparts in the non-fluoridated area in 2010. Those living in families with income under one per capita minimum wage had a higher value in untreated dental caries in the non-fluoridated area at both years and in the fluoridated area in 2010 (Table 2).

Table 3 shows the crude and adjusted Difference-in-Differences analysis outputs in mean values of DT across income and racial subgroups according to exposure to CWF from 2003 to 2010. The crude and adjusted outputs showed significant differences only in the non-fluoridated area. Adolescents living in families included in the higher income group and those self-declared Whites had significant DT mean reductions, respectively, 12.4% and 14.8% than their counterparts. Contrarily, the differences were non-significant in the fluoridated area although more favourable for Whites [$\beta = -0.34$ (-0.74, 0.04)] than Blacks/Browns. Supplement 1 showed an analysis of the missing values. Sensitivity analysis based on percentages of individuals with at least one untreated decayed tooth confirmed our findings (Supplement 2). While in the fluoridated area, the reduction in the proportion of people with at least one decayed tooth was similar for racial and socioeconomic groups, in the non-fluoridated area, the reduction was more prominent for wealthier and Whites.

Discussion

The exposure to water fluoridation showed no difference in DT reduction between income subgroups, suggesting favourable trends to health equity amongst Brazilian adolescents while in the non-fluoridated area favoured wealthier and Whites.

In both areas, we observed a reduction of mean decayed teeth. This declining trend has been observed worldwide due to the widespread use of fluorides². Investigations showed

that dental caries have also been reducing in the overall young Brazilian population, but these improvements have not been similar among socioeconomic groups^{19,28}. However, these studies did not compare the changes according to exposure to CWF. Our findings showed similar decreases across socioeconomic subgroups in the mean values of DT in the fluoridated area, while the differences remained in the non-fluoridated area. In a study with Australian children, all inequality indexes indicated that caries experience was concentrated among lower-income groups and was lower in the fluoridated than in the non-fluoridated area²⁹.

Regarding racial subgroups, although the differences in DT reduction have been non-significant, they were as wide as those observed for income subgroups. Considering the rates of individuals with at least one untreated decayed tooth (Supply 2), the differences in reduction were compatible with similar values for both income and racial subgroups in the fluoridated area contrarily to the non-fluoridated area which reductions were higher for wealthier and Whites. As the income differences were estimated adjusting by racial groups and vice versa, this finding could mean that income differences are more amenable by CWF than racial differences, a hypothesis to be confirmed for further DiD analysis. Previous evidence comes from cross-sectional studies. One showed that CWF did not reduce racial inequalities significantly³¹, while the other observed no significant ethnic inequalities in deprived settings with CWF⁹.

Race has emerged to explain the persistence of health inequalities in some contexts³². The relative disadvantage that racial groups face in terms of oral health has been interpreted as stemming from structural or macro-level processes. This includes dental care, living in deprived neighborhoods, and restricted access to dental care and fluoridated piped water³³. These inequalities persisted in the adjusted models for gender, schooling, income and age. In general, those from higher socioeconomic status (SES) know about

the risks and have the resources—money, knowledge, power, prestige, and beneficial social connections—to engage in the prevention than treatment³⁴. Our study demonstrated that even adjusting for schooling and income (an inherent part of SES), lower health gain for Browns/Blacks than Whites was observed in the non-fluoridated area. In other words, it means that race and SES are not overlapped. One possible explanation could be related to difficult access to fluoridated toothpaste by different racial groups³⁵.

In the non-fluoridated area, the reduction of mean untreated decayed teeth was higher for wealthier than their counterparts. Decomposition analysis on dental caries experience among 9 to 14-y-olds Australian children showed that exposure to CWF explained one third of area-level income inequalities³⁶. Other studies have shown the effect of CWF on reducing dental caries in the context of multiple sources of fluoride^{5,8,14,15,37}. Do et al. (2018) found that income-related inequality in caries was lower in fluoridated than in non-fluoridated areas for Indigenous and non-Indigenous children. One study showed benefits associated with higher lifetime exposure to CWF even adjusting for socioeconomic conditions¹⁴, and another showed potential benefits of CWF on income inequalities³⁸, corroborating our findings.

Our study has some strengths and limitations. First, this Difference-in-Differences approach used data from two national epidemiological surveys that accurately reflected the country's characteristics as a whole. We utilized data from only 50 cities that participated in 2003 and 2010 surveys, so the cluster units (cities) were the same. Second, water fluoridation levels were determined using different data sources, thereby improving their reliability. Third, distinctly from other dental caries measurement tools, the selected outcome (mean untreated decayed teeth) measures the current disease severity that is an indicator less affected by differences in access to oral healthcare and by the dentist's decision to restore. The outcomes (mean untreated decayed teeth) across socioeconomic

and racial subgroups according to exposure to CWF were compared during seven years. They showed the impact of CWF independently of other dental caries determinants affecting both the exposure and non-exposure group¹⁶. One limitation was that data on exposure to fluorides at the individual level were not available. In the DID approach, the baseline data is expected to be at the beginning of the intervention and in the current study's design, we are sure that the intervention began at least three years before, according to available official data from national sanitation research gathered at 2000. As the investigated intervention was measured in a defined age group, exposed and non-exposed to CWF during the group's lifetime, the difference between those times does not undermine the analysis. The ideal picture would be that all cities included in the fluoridated area had begun the public policy implementation simultaneously and at least ten years before so that effects could be observed at the permanent dentition of 15-19-year-old adolescents. As this paper is the first reporting CWF's effect by a DiD analysis, further studies are needed to elucidate points not addressed herein. The complexity involved in racial classification in Brazil must also be highlighted^{9,39}; however, it is the best data representing the Brazilian population of adolescents as a whole.

In conclusion, the similar reduction in decayed teeth across income subgroups suggests the beneficial effect of CWF to tackle income inequalities in dental caries within a 7-year timeframe.

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Tables

Table 1. Descriptive characteristics and weighted means of DT of Brazilian adolescents (n=7198)

Individual variables	n=7198	% (95%CI)	DT
			mean (95% CI)
Ethnic Group 2003 (n=3178)			
Whites	1254	41.5 (36.7-46.7)	1.94 (1.50-2.37)
Browns+Blacks	1924	58.5 (53.6-63.3)	2.23 (1.96-2.50)
Ethnic Group 2010 (n=4020)			
Whites	1653	43.0 (40.5-45.6)	1.24 (1.04-1.44)
Browns+Blacks	2367	57.0 (54.4-59.5)	2.04 (1.86-2.23)
Per capita Income 2003			
under minimum wage	1641	48.6 (43.7-53.4)	2.57 (2.19-2.94)
At and above minimum wage	1537	51.4 (46.5-56.3)	1.67 (1.41-1.93)
Per capita Income 2010			
under minimum wage	2158	54.2(51.6-56.7)	2.08 (1.88-2.29)
At and above minimum wage	1862	45.8 (43.3-48.4)	1.24 (1.08-1.41)
Fluoridation 2003			
No	1596	27.5 (24.5-30.6)	2.83(2.60-3.07)
Yes	1582	72.5 (69.4-75.5)	1.83 (1.52-2.14)
Fluoridation 2010			
No	1770	26.7 (24.8-28.8)	2.39 (2.17-2.62)
Yes	2250	73.3 (71.2-75.2)	1.44 (1.28-1.61)
DT – Mean decayed teeth			

Table 2. Decayed teeth weighted means of Brazilian adolescents, according to Fluoridation contexts (n=7198)

Individual variables	DT		DT	
	n	Non-Fluoridated	n	Fluoridated
Ethnic Group 2003	1596		1582	
Whites	422	2.47 (2.09-2.85)	832	1.81 (1.29-2.35)
Pardos+Blacks	1174	2.98 (2.69-3.27)	750	1.85 (1.49-2.21)
Ethnic Group 2010	1770		2250	
Whites	573	1.51 (1.19-1.84)	1080	1.17 (0.96-1.53)
Pardos+Blacks	1197	2.85 (2.57-3.13)	1170	1.68 (1.45-1.93)
Per capita Income(equivalized) 2003	1596		1582	
under minimum wage	937	3.11 (2.81-3.41)	704	2.28 (1.73-2.85)
above minimum wage	659	2.41 (2.20-2.80)	878	1.47 (1.17-1.79)
Per capita Income(equivalized) 2010	1770		2250	
under minimum wage	1019	2.96 (2.64-3.28)	1139	1.75 (1.50-2.01)
above minimum wage	751	1.69 (1.41-1.98)	1111	1.09 (0.89-1.28)

Table 3. The Difference-in-Differences analysis in average values of number of DT amongst Brazilian adolescents and stratified by exposure to CWF (n=7198)

Mean Decayed Teeth Stratified by exposure to CWF									
Non-Fluoridation Areas									
Socioeconomic groups	n	Mean 2003	n	Mean 2010	Diff-in- Diff ^a (β)	β ^a (95% CI)	Diff-in- Diff ^b (β)	β ^b (95% CI)	%D
under 1 MW	937	3.11	1019	2.96	-0.30	−0.57; -0.02	-0.26	-0.53; -0.01	-12.45%
(R) above 1 MW	659	2.41	751	1.69					
Racial groups									
Browns+Blacks	1174	2.98	1197	2.85	-0.44	-0.74; -0.14	-0.40	-0.69; -0.11	-14.77%
(R) Whites	422	2.47	573	1.51					
Fluoridation Areas									
Socioeconomic groups									
under 1 MW	704	2.28	1139	1.75	-0.04	−0.43; +0.35	-0.05	-0.45; +0.35	-2.72%
(R) above 1 MW	878	1.47	1111	1.09					
Racial groups									
Browns+Blacks	750	1.85	1170	1.68	-0.34	-0.77; +0.07	-0.34	-0.74; +0.04	-18.38%
(R) Whites	832	1.81	1080	1.17					

β - Crude coefficient; %D - Percentage of Difference (coefficient β / baseline mean of reference (R) group) - MW – Per capita minimum-wage. DT – decayed teeth;
 β^a - unadjusted β^b - adjusted for schooling, age, sex, income (if analyzing racial groups) and racial groups (if analyzing income)